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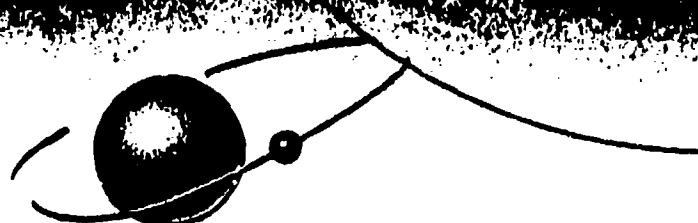
## No. 73

# THE GREEN GLOW DIFFUSION PROGRAM
## Volume I

Edited by
Morton L. Barad
James J. Fuquay

January 1962

**GRD**

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Geophysical Research Papers
No. 73

# THE GREEN GLOW DIFFUSION PROGRAM
## Volume I

Edited by ●

Morton L. Barad
James J. Fuquay*

January 1962

*Hanford Laboratories
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## Abstract

The GREEN GLOW program was a field investigation aimed at providing experimental data on the diffusion of an aerosol over a 16-mile range. The experiments, 26 in number and all during nighttime hours, were conducted on the Hanford reservation of the U. S. Atomic Energy Commission, near Richland, Washington during the Summer of 1959.

The report of this program will be published in two volumes. This first volume includes descriptions of the field site, forecasting techniques, diffusion-measuring methods, meteorological equipment, and operating procedures during the experiments. The second volume contains tabulations of the diffusion data and the meteorological data collected during the program.

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# THE GREEN GLOW DIFFUSION PROGRAM

## I Introduction

Morton L. Barad
Geophysics Research Directorate

Glenn R. Hilst*
Hanford Laboratories
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During the Summer of 1959 a field program designed to increase our knowledge of atmospheric diffusion processes in the lower atmosphere was conducted near Richland, Washington. The program was jointly sponsored by the U. S. Air Force and the U. S. Atomic Energy Commission. It was nicknamed "Green Glow" for ease of reference. The nickname reflects the use, as a tracer, of zinc sulfide particles, which exhibit a green fluorescence under ultraviolet light.

The primary objective was to determine the rates of horizontal and vertical diffusion of the particulate tracer as a function of meteorological conditions. It was hoped that the design of the experiments would also provide greater insight into the deposition problem and would also shed light on the relationship between the time at which tracer particles first reached the two outer arcs and attendant meteorological parameters.

In an earlier Air Force Program, Project Prairie Grass,[1] dosages of a tracer gas had been measured at a height of 1.5 m above ground out to distances of 800 m from a continuous point source. These measurements permitted the calculation of the horizontal dispersion of the tracer. In addition at six locations on the 100-m arc, vertical distributions were determined from samples collected on towers. Seventy experiments, conducted both in the daytime and at night, were carried out over a very flat prairie covered with short grass.

In some ways the design of the Green Glow experiment was an extension of that of Prairie Grass. Measurements of dosage at a height of 1.5 m were made not only at 200 and 800 m (two of the Prairie Grass distances) but also at distances of 1600 m, 3200 m, 12.8 km, and 25.6 km. Samples at this height were collected at 533 sampling positions. Vertical distributions of dosage were determined from samples collected on five poles or towers erected on each of the first four arcs. The poles or towers were $8^\circ$ apart, and each was equipped to provide 15 samples in the vertical. The 26 experiments, conducted only at night, were carried out over slightly rolling terrain covered with sagebrush and desert grass on the Hanford reservation of the U. S. Atomic Energy Commission near Richland, Washington.

The design of the Green Glow program was a joint effort by personnel of the Hanford Laboratories of General Electric Company, and the Geophysics Research Directorate (GRD) of Air Force Cambridge Research Laboratories. The General Electric group was responsible for preparing the site, purchasing and installing equipment for the diffusion experiments, conducting these experiments, measuring meteorological parameters at several locations on the reservation, and reducing the diffusion and meteorological data it had collected. The GRD group was responsible for coordinating the efforts of the participating organizations during experiments and for assisting in the diffusion experiments and in the reduction of the experimental data. A team from the Texas A&M Research Foundation made micrometeorological measurements at two locations on the reservation. * The 6th Weather Squadron (Mobile), 4th Weather Group, Air Weather Service provided special rawinsonde measurements during diffusion experiments.

The following is a list of the personnel who participated in the field program:

6th Weather Squadron (Mobile), 4th Weather Group, Air Weather Service

       M/Sgt D. Brantley
       S/Sgt O. Cagle
       A/1C S. A. Heinrichs
       A/1C C. E. Lee

---

\* The locations of the two Texas A&M stations are shown in Fig. VI-1 (page 44 )

Texas A&M Research Foundation

| | |
|---|---|
| T. P. Airhard | G. L. Holligan |
| R. D. Boudreau | W. L. Markillie |
| W. H. Clayton | D. L. McGuire |
| R. G. Courim | J. D. Merryman |
| W. Covey | W. R. Phillips |
| T. L. Ferguson | A. M. Scott |
| J. L. Goldman | H. A. York |
| S. J. Hall | |

Geophysics Research Directorate

M. L. Barad
W. P. Elliott, Jr.
D. A. Haugen
Capt. D. W. Stevens

Hanford Laboratories, General Electric Company

| | |
|---|---|
| P. L. Barr | R. N. Martin |
| G. G. Boire | P. W. Nickola |
| R. L. Conley, Jr. | C. A. Rankin |
| C. E. Duchon | R. L. Ross |
| C. E. Elderkin | O. D. Russell |
| R. J. Engelmann | M. F. Scoggins |
| J. J. Fuquay | C. L. Simpson |
| G. R. Hilst | J. W. Sloot |
| D. M. Hughey | D. W. Tuttel |
| R. LaMonte | |

The objectives in this paper are (1) to describe the site and the procedures and techniques used in planning and conducting the diffusion experiments, in measuring meteorological parameters, and in reduction and processing of data; and (2) to present tabulations of the data collected. The first objective is reported in this first volume; the second volume, when published, will complete the second objective. The descriptions of procedures and techniques used by the Texas A&M Research Foundation in its field measurements and in data reduction are so voluminous that they have been presented separately.[2, 3]

It is not the intention in this two-volume paper to present analyses of the data, to evaluate existing diffusion models, or to develop new models. Such efforts have been initiated by the research teams that participated in the field program. It is expected that their findings will be published in professional journals and in in-house reports. We hope that other research groups will also use the rather unique data published here in their studies of the diffusion problem.

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## References

1.  Barad, M. L. (Editor), "Project Prairie Grass, A Field Program in Diffusion," Geophysical Research Papers No. 59, vols. I - III, Geophysics Research Directorate, Air Force Cambridge Research Laboratories (1958).

2.  Clayton, W. H. and J. D. Merryman, "Design of the Mobile Micrometeorological Stations Employed on Project Green Glow," Final Report, Contract No. AF19(604)-4562 Texas A&M Research Foundation (1960).

3.  Clayton, W. H., "Micrometeorological Data, Project Green Glow," Scientific Report No. 1, Contract No. AF19(604)-5527, vols I and II Texas A&M Research Foundation (1960).

# II Description of the Hanford Area

James J. Fuquay
Hanford Laboratories
General Electric Company

The Hanford reservation, located in a semiarid region of Southeastern Washington, is essentially a basin bounded on all sides by elevated terrain (Fig. II-1). The center of the reservation is about 700 ft above mean sea level. South and southwest of the reservation are the Rattlesnake Hills, which reach an elevation of about 3500 ft. On the west is the Yakima Range, which also reaches elevations of about 3500 ft. Extending the full width of the reservation on the north are the Saddle Mountains, which reach elevations of 2400 to 2700 ft north of the 100 areas. The terrain on the northeastern and eastern rims of the basin is about 1100 ft above mean sea level, extending southward to a point across the Columbia River east of 300 Area. Internally the area is roughly divided by Gable Butte and Gable Mountain, which rises to an elevation of about 1100 ft. The Columbia River flows through the northern part of the reservation, thence southward toward the 300 Area and Richland. The terrain to the north and east of the river rises sharply to form an almost continuous bluff rising 400 to 600 ft above the river level. These bluffs present a major obstacle to wind flow in the lowest few hundred feet above the surface except parallel to the obstructions.

Several major breaks in the sides of the basin are present and these are of particular interest because of the natural channeling of the air flow through them. The major openings into the area are (1) the Beverly Gap on the northwest side, a narrow gorge through the Saddle Mountains, formed by the Columbia River, (2) the Ringold Coulee on the east side, which permits drainage of the extensive flat lands to the east of this area into the Columbia, (3) the broad valley to the south of the area, which permits generally unobstructed flow from the area southeastward, and (4) the Benton City Gap, a relatively shallow but narrow valley formed by the Yakima River, which connects the area and the Yakima Valley.

These variations in topography are largely responsible for the fact that the general wind-flow patterns appearing on weather maps of the Northwest fail to indicate unique patterns of air flow in the first few hundred feet of the atmosphere in the Hanford Works area except during very strong winds. These topographic variations not only obstruct or channel the air flow but also lead to local valley-slope circulations caused by differential heating or
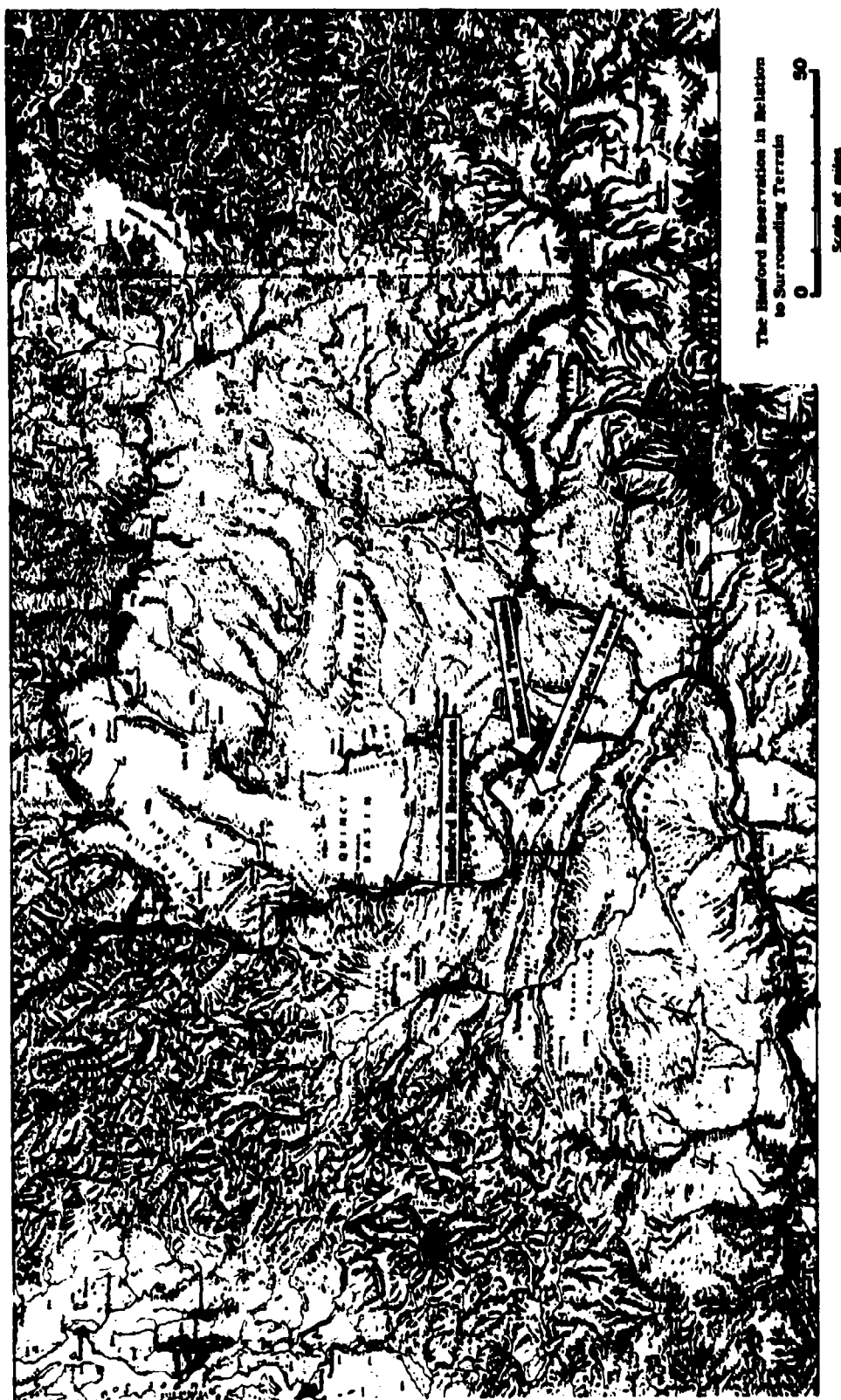
Figure II-1. The Hanford Reservation in Relation to Surrounding Terrain

cooling of the terrain.* These topographic effects give rise to a nocturnal drainage wind over the Hanford reservation that flows from northwest to southeast across the central portion of the area.

The site chosen for the sampling grid was on the valley floor; and it was located so that the base line of the grid approximately paralleled the major ridges and extended southeastward from the Meteorological Tower area. Vegetative cover was sagebrush of 1 to 2 m height, interspersed with desert grasses. The area was relatively flat, dropping about 300 ft in 16 miles from the source area; 100 ft of this drop occurred in the area 4 to 6 miles from the source. Smaller-scale undulations in the terrain, similar to sand dune characteristics, occurred at distances beyond 6 miles in some directions. From areal photographs the general appearance of the surface appears somewhat globular because of the individual clumps of sagebrush.

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* Jenne, D. E., and R. E. Kerns, "A Climatological Study of the Hanford Area," HW-57722. Available from OTS, Dept. of Commerce, Washington 25, D. C. (1959).

# III Wind Prediction for the Green Glow Program

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Hanford Laboratories
General Electric Company

## INTRODUCTION

An initial consideration in planning and executing an experimental program that is dependent on selective characteristics of the lower atmosphere is the probability of occurrence of the desired properties. One must determine whether operational decisions will be based on the climatology of the season or the latest observational data available. This determination must await a comparison of climatological summaries on the one hand and a goodly number of subjective, semi-objective, objective, and just plain observational techniques on the other. To evaluate these approaches, careful consideration must first be given to the predetermined criteria for successful operation.

Conditions were considered operational if, under stable atmospheric conditions, the winds were sufficient to transport a generated plume over a stationary grid of some 16 miles extent. The grid for the program forces limits for acceptable directions for the wind at any point. Furthermore, favorable conditions must persist long enough for the plume to completely traverse the outer arc. Thus, for any specific operation, the time required for completion is somewhat inversely proportional to the down-course component of the wind velocity. Finally, since the effects of "washout" by rain were not included within the scope of this program, periods during which precipitation occurred were not favorable.

The above criteria are met frequently during July and August nights in the Hanford area. The climatology of the Hanford Tower brings forth three facts. First, only rarely are unstable temperature stratifications observed at night. Second, winds from the northwest quadrant have been observed more than 75 percent of the time at night. Finally, rainfall is light and infrequent — observed in the form of showers of short durations. The fact that the average sky cover for a July or August day is only 2/10 to 3/10 indicates the fair-weather-type model characterized by nighttime stability and related wind structure is applicable. A true measure of the conformity of the climatology to the standards must account for the time variation of all the variables taken together.

One way to assess the probability of a favorable operating situation is to plot the components of the velocity and a measure of the stability serially

over a period of time, and then to measure the favorability of any particular night by considering all the variables taken simultaneously. The dependent sample in this instance was made up of data for all the July and August nights for the period 1952-1958. The velocity components plotted were derived from the hourly average-observed 50-ft wind from the 410-ft Hanford Tower. The temperature difference between the 3- and 200-ft levels of the tower $(T_{200} - T_3)$ was used as the measure of stability; and notation was made on each night in which rain was observed. From these graphs the nights could be divided into three broad classifications from which some expected values could be derived.

Each night was classified as stable, slightly stable, or unfavorable. The first two are characterized by having fulfilled the stability criterion for operational conditions, whereas the last has not. The differences, however, between "stable" and "slightly stable" nights are perhaps greater than the arbitrarily assigned terms might imply. Stable nights were those character-ized by 50-ft winds with speeds averaging 12 mph or less and associated temperature differences greater than +3 F°. The vertical wind-direction shear in these cases was often quite large although this property was not considered in the classification. On the other hand, slightly stable nights were characterized by winds generally averaging more than 12 mph and exhibiting considerable gustiness. The observed temperature difference, $T_{200} - T_3$, in these cases was -0.5 to 3.0 F° and the wind-direction shear was small. The plan was to make a realistic appraisal of each situation by evaluating its properties in terms of the atmospheric conditions deemed pertinent to the diffusion program. On the basis of this classification, for the average summer (July and August) in the sample, 12 nights were stable, 30 were slightly stable, and 20 were unfavorable. The variation of the numbers between months and years was reasonable small. Assuming that these averages may be used as expected values, it remains to be resolved as to what method should be employed to determine the operational night in a manner that will take advantage of most of the "stable" cases and minimize attempts to operate during those that are unfavorable.

Consider the following question: What results can be expected if the program is operational every other night? In this instance the decision of operation is not based on any meteorological information at all. If the data from the 7-year sample may be extended, a prediction is obtained for the 2-month period of 6 stable, 15 slightly stable, and 10 unfavorable nights. These figures were obtained by examining every other day in the sample. The fact that they are exactly half of the normals is coincidental. The serial

plot of the variables show that stable nights often occur successively in a series of two, three, or four nights. The same persistent characteristic is also true of the unfavorable condition. Experience at Hanford has shown that these periods of favorable and unfavorable conditions are related to specific synoptic sea-level pressure patterns suggesting that the development of this relationship will provide the basis for a decision-making scheme based on over-all climatological statistics.

The problem of prediction of the wind velocity and thermal stability at any point on the course has so far been neglected in this discussion. It is, of course, intended that once the plume is emitted its trajectory will be within the defined grid until its trailing edge has crossed the sampling positions at 16 miles. The emphasis was placed on obtaining expectancies of the initial conditions near the source (Hanford Meteorology Tower) since the entire trajectory is so dependent on its direction shortly after its emission. No emphasis was placed on developing techniques for the over-all trajectory prediction, because the position of the grid is such to embrace almost all plumes when conditions are favorable at the source. This was suggested by Scoggins[1] in a 5-year summarization of the frequency of observed winds at eight observation points within and around the grid at times when conditions for emission were favorable at the source. Therefore, given the wind velocity at the source, the most probable trajectories can be deduced. One factor which is not accounted for here is that observed speeds during favorable conditions generally diminish with time and distance downwind from the source so that the time required for the plume to traverse the last eight miles can be much greater than that required for the first eight.

## TOPOGRAPHY AND THE DRAINAGE WIND

The evening summertime winds that occur in the Hanford area are affected by the local topography. A brief description of the topography and the onset of the down-valley wind will serve to point up many of the problems that are involved, although, because of sparsity of observations, causalities are not necessarily implied.

The down-valley wind that is observed in the evening has been called a drainage wind because of the recognition that it results largely from areal density differences created by unequal daytime heating and nighttime cooling. The wind pattern is characterized by a diurnal variation having a minimum velocity in the early morning hours and a maximum velocity in the early evening. The pattern is unique to summer alone, having its onset in June, and rarely is observed in September. The winds occur night after night,

often with peak gust exceeding 30 mph. Table III-1 shows the frequency of
peak gust ranges observed in August 1956, which is a representative month,
during the period 2000-0400 hours. Observed winds were from the north-
west, west-northwest, and west.

TABLE III-1

Frequency of Peak Gust Ranges Observed in August 1956

| Peak Gusts | Frequency |
|------------|-----------|
| 0-9 | 4 |
| 10-19 | 7 |
| 20-29 | 8 |
| 30-39 | 6 |
| 40-49 | 1 |
| TOTAL | 26 |

The peak gusts are most often observed at the Hanford Tower for the period
of 2100-2200 PST with an abrupt onset of the drainage wind. By 2400, rapid
diminishing takes place to a minimum in early morning. Daytime winds
frequently become easterly and remain so until the onset of the drainage
wind and the cycle is repeated.

Figure II-1 (page 6 ) shows the topography of the Eastern Washington
area and is helpful in ascertaining those areas most likely to be the source
of the drainage wind. Significant are the elevation differences between the
Columbia River Basin lands and the Cascade Range to the west. The eleva-
tion changes about 6000 ft in the 60-mile distance between the Hanford Tower
and the Cascades. Greater slopes are observed in the river valleys that
drain out from the Cascades. The most prominent of these is that of the
Columbia River, which parallels the eastern foothills of the Cascades from
the Canadian border southward into the Hanford area where it bends again
westward to the Pacific Ocean. All along its path are numerous valleys
extending down from the highest regions of the Cascades. Nearer Hanford
are smaller groups of hills and mountains that affect the wind pattern over
the Hanford area. The most prominent of these is Rattlesnake Mountain
(elevation 3560 ft), which is five miles southwest of the Hanford Tower.
Synoptic observations suggest the hypothesis that winds observed at Hanford
result directly from differences between Basin and Cascade temperatures,
with some influence exerted by land forms nearer the Hanford area.

Some concepts of the initiation and development of the drainage wind
over the Eastern Washington area may be inferred from the few observa-
tions which are available. The complexity of the topography necessitates
an observational network comprised of many times the number of stations
that presently exist before specific results can be obtained. However a

pattern of development may be described that is consistent with dynamic principles and the sparse observations that are available. Differential day-time heating creates density difference between the mountains and the basins that eventually brings about the onstart of the air drainage. Maximum temperature differences of over 30 $F^o$ are not uncommon between the Hanford Tower (elevation 747 ft) and the Stampede Pass station (elevation 3800 ft) during the summertime. On such occasions moderate westerly drainage winds are observed early in the mountain passes, but winds in the flat eastern portions of the state are variable and light. As the day proceeds, Ellensburg, Washington (elevation 1735 ft), located 45 miles southeast of Stampede Pass, experiences fresh westerly winds. Presumably, near sunset, this surge is felt still farther eastward as it spills over the lower elevations and down into the lowlands of the Columbia River. The drainage effect is seldom experienced east of the Columbia River. This proposed model is based on observations from a few widely separated stations and upon the growth of the vegetation in areas near Ellensburg and Beverly, a gap 30 miles northwest of Hanford. As a result of the intensity and frequency of the drainage winds in these areas, trees and brush grow obliquely with their tops pointing to the southeast. The evidence is strong that air drainage originates in the valleys of the Cascades, although the specification of particular source regions is difficult because of the sparsity of observations. In fact the paucity of observations has proved the greatest obstacle to improving the forecasts of winds for the Hanford area.

The effects of density difference have been considered independently of other forces that are undoubtedly operating in this process. However the complexity of the situation does not warrant the exclusion of any force from consideration. For example the pressure gradient has long been suspected as influencing greatly the resultant Hanford winds. Several prediction techniques have been developed which correlate positively a measure of the pressure gradient with observed Hanford winds. It is well known that situations which have been ideally described as drainage types can be identified with distinct types of sea-level pressure fields. Because this association is known to exist, and since little can be inferred concerning the density field in the Cascades from the existing observations, a measurement of the pressure field has become the basis for development of prediction schemes for the wind at Hanford.

## PREDICTION TECHNIQUES

A fundamental and oftentimes rewarding procedure leading to the issuance of a wind forecast is that of the subjective accounting for all those

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factors which theory and experience indicate are important. The forecaster draws mainly from experience, mentally organizing, classifying, and weighting the data. This technique must not be considered too lightly, particularly when forecasting elements at specific locations under conditions where simplifying assumptions are not valid for the hydrodynamic equations. Factors that are usually considered can be organized into a set of "rule-of-thumb" statements, but in reality there are so many exceptions to these rules that confusion results from the complexity of such a tabulation.

Still the mind is capable of assimilating masses of information on pressure and temperature fields, velocity fields and the variation with time and space of these elements, and weighting observations in an experienced manner to provide an "acceptable" level of prediction. This approach was used for the first approximation in the issuance of the final prediction for the diffusion experiments.

Greater consideration was given to the velocity field and its change taken at 1-hr intervals. In this way the time of the beginning of drainage at stations west of Hanford could be observed and the time of expected arrival better estimated. Also, the magnitude of the velocity of the wind is an indicator of the magnitude to be expected at Hanford. If drainage has not begun in the mountain valleys by late afternoon, the probability of stable or slightly stable drainage conditions at Hanford is small. On the other hand, when speeds of 25 mph or more are observed at Ellensburg by late afternoon, slightly stable conditions can be expected at Hanford almost without exception. These are but a few examples of the guided application of experience. This technique served the following purposes: (1) it was used for the initial prediction; (2) it was used as a deciding factor when objective methods disagreed; and (3) it was applied periodically after the issuance of the final forecast to appraise the change in conditions. Major shortcomings of the technique are: (1) the prediction is best phrased in trends and generalities and, therefore, loses some value for planning of a specific operation; (2) the probability of occurrence is loosely inferred with "carefully chosen" terms; and (3) much of the experience gained through use is of little value to others because of its subjectivity. These short-comings strongly indicate a real need to develop useful objective techniques that will partly eliminate some of these objections.

In 1957 Simpson and Thorp[2] devised a prediction scheme for the Hanford Tower that correlated the wind velocities observed at Hanford with a measure of the pressure gradient. Fast moving and rapidly developing pressure systems were specifically excluded from consideration, but this

was not a severe handicap since the summertime pressure field remains
sensibly constant. Since 1957 the technique has been thoroughly tested and
accepted as a standard consideration for prediction of winds at Hanford.
The essential features of the method are summarized in the following para-
graphs.

The basic assumption in the development of the technique is that the
local pressure gradient is by far the most significant driving force for the
winds. It has long been recognized that the local pressure field is often
quite irregular with cells developing within a small area. Since the con-
sideration of the position and intensity of these cells resulted in significantly
improved predictions over those based on smoothed analyses, the parameters
measuring the gradient were derived from the sea-level pressure reports
from six stations, which experience had indicated to be consistently signifi-
cant. Table III-2 lists the six stations from which data were obtained and
Fig. III-1 shows their positions (relative to the Hanford Tower).

TABLE III-2

Stations used in the surface
wind predictor system for Hanford

| Station | Elevation above MSL (ft) | Distance from Hanford (mi) | Direction from Hanford (deg) |
|---|---|---|---|
| Hanford, Wash. | 727 | | |
| Pendleton, Ore. | 1495 | 70 | 150 |
| Spokane, Wash. | 2365 | 130 | 055 |
| Omak, Wash. | 1232 | 140 | 360 |
| Seattle, Wash. | 388 | 145 | 295 |
| Portland, Ore. | 39 | 160 | 245 |

Figure III-1. Observed Relation-
ships Between the Average
Sea-Level Pressure Gradient
Observed at 1630 PST and the
200-Foot Wind Direction at
Hanford During the Ten-Hour
Period Following These Times
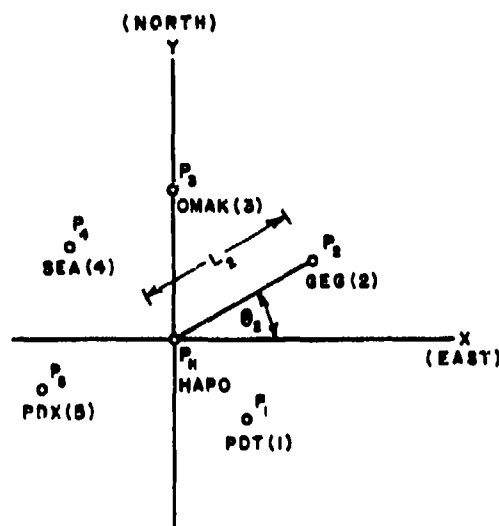
With use of the sea-level pressure reported for each of the stations shown in Fig. III-1, the representative pressure gradient across Hanford was determined by resolving the east-west and north-south components of the pressure gradients between Hanford and each of the other five stations, and then summing these components.

Using the notation in Fig. III-1, the two components of the mean pressure gradients are derived from

$$G_x = \Sigma_i \frac{P_H - P_i}{L_i} \cos \theta_i \tag{1}$$

and

$$G_y = \Sigma_i \frac{P_H - P_i}{L_i} \sin \theta_i \tag{2}$$

where subscript i refers to the individual station (1 = PDT, 2 = GEG, etc.), $G_x$ and $G_y$ are the summed orthogonal components of the pressure-gradient vector, which are assumed to be representative for Hanford. The values of $G_x$ and $G_y$ determined from these equations have been plotted against the 200-ft wind velocity observed during each of the 10 hrs following the issuance of the map from which the data were taken. The results of these analyses for the 1630 PST time are summarized in Figs. III-2 and III-3. The entries of directions and speed intervals are those most frequently observed (modal). The percent frequency of that speed or direction is also given along with the total number of hours of data used for the calculations. The entry includes all mean hourly directions within $34°$ of the reported value, allowing for some overlap of directions. For example, the frequency given for a south direction is actually the combined frequencies that were observed for SSW, S, and SSE within that region; whereas the frequency given for a SSW direction is the sum of the frequencies that were observed for S, SSW, and SW.

In one area, in which the frequency of the modal direction was less than 30 percent, the winds are termed unpredictable (U). Figure III-3 shows that the speeds for this area are low so that the main characteristic over the 10-hr period is the absence of persistence.

The two nomograms considered together allow for a general classification of specific pressure distributions using the criterion established in an earlier section. For example, if the computed values place the resultant in the regions where the modal direction is SW, ESE, or U, the probability of winds ever being on-course are small so that the situation must be considered unfavorable. Stable conditions, on the other hand, are highly
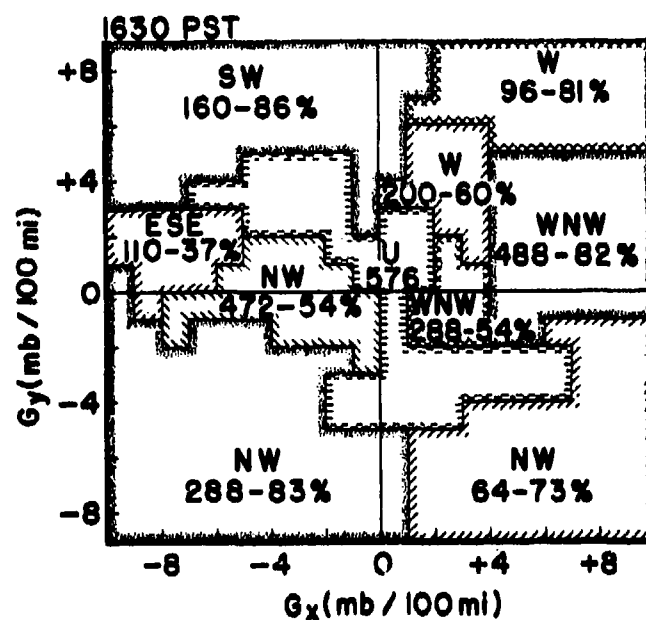
Figure III-2. Observed Relationships Between the Average
Sea-Level Pressure Gradient Observed at 1630 PST and
the 200-ft Wind Direction at Hanford During the 10-Hour
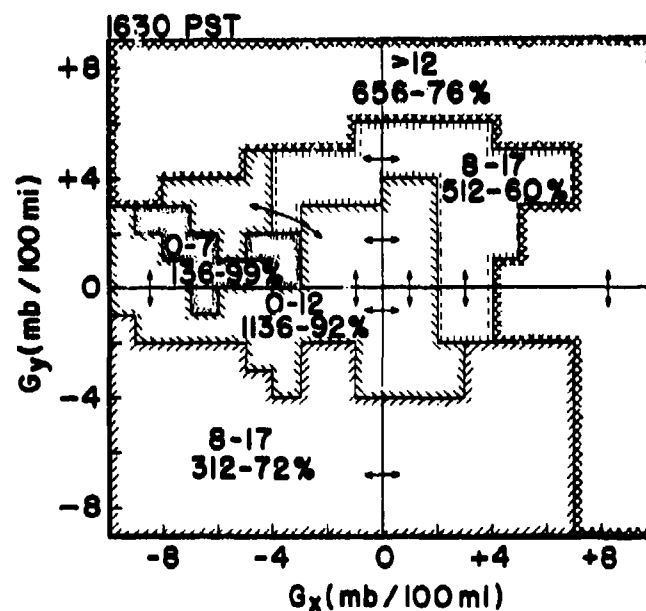Period Following These Times



Figure III-3. Observed Relationships Between the Average
Sea-Level Pressure Gradient Observed at 1630 PST and
the 200-ft Wind Speed at Hanford During the 10-Hour
Period Following These Times

probable in the areas where NW winds of speeds 8-17 mph are modal, and
slightly stable properties are characteristic of the W and WNW winds with
average speeds greater than 12 mph. The three remaining areas of W,
WNW, and NW are related to conditions of stability and slight stability, but
the modal probabilities indicate that a careful examination involving other
known factors should be made. These nomograms serve to demonstrate the
general relationship between pressure and the components of wind velocity.
For the actual prediction, however, the areas were sub-divided many times
using the dependent data as basis, resulting in complex diagrams. Because
of their complexity, these "working" nomograms have not been included.
However the method as illustrated with Figs. III-2 and III-3 is the same and
demonstrates the approach to the problem. In addition the nomograms
contained a record of all the departures that were available so that for every
computation the frequencies of all observed directions and speeds were
known. The use of this information in conjunction with the observations
available at the time the forecast was issued had proven in the past to be an
efficient approach.

The method is useful for both the over-all assessment of the probabil-
ity of success on any given night and for anticipating temporal variations in
the velocity by using the additional data. Essentially it is an attempt to
extend the results expressed in terms of frequencies obtained, by relating
the observed velocities to measures of the pressure gradient. Two short-
comings are noted. First, the most effective application of the technique
requires a subjective analysis of factors not directly included in the method.
That is, the data are expressed in the form of trends and long period
averages yielding very little specific information in those areas where the
frequency of occurrence is low. Second, the observed velocity is that of
the 200-ft level of the Hanford Tower. This necessitates some approxima-
tion to obtain velocity predictions near the surface.

## EMPIRICAL ORTHOGONAL FUNCTIONS

In 1956, Lorenz[3] introduced a statistical method for specifying
quantitatively the field of a continuous variable which is applicable to this
problem. He was specifically concerned with reducing the number of varia-
bles required to accurately specify a series of "maps", and then relating
the specifiers of the "flow pattern" to the predictand, which in the Hanford
problem is the wind velocity. This work was an extension and refinement
in the studies of synoptic climatology which began in 1948, when Wadsworth
and Bryan developed a completely objective technique for expressing a
pressure or contour pattern by means of an equation using statistical

methods. Historically, since that time, significant contributions have been made by universities, government agencies, and private groups. A review of this development would be an extensive task and not in the scope of this paper. However, such a review has been made by Simpson,[4] and detailed reports of the investigations have been published by Lorenz,[3,7] Shorr,[6] Malone,[8] and others. Here, a brief description of the recent works of Lorenz and Shorr will be given since the study for Hanford closely follows their development.

The M. I. T. group in their study wanted to specify the sea-level pressure field over a period of time with as few variables as possible without seriously affecting the accuracy of the representation. These variables, which were derived from sea-level pressure values put into a matrix, were then linearly related to the predictand in an equation of the form

$$Y = A_0 + A_1 Q_1 + A_2 Q_2 + A_3 Q_3 \cdot \cdot + A_N Q_N \quad , \tag{3}$$

where Y is the predictand, $Q_i$ is the specifier of the pressure pattern, and $A_i$ is the coefficient to be determined. Equation (3) was solved by the Crout[5] method. The specifiers of the pressure pattern, called empirical orthogonal functions or Q's, are derived using the statistical technique of diagonalization. Diagonalization is essentially a matrix solution that enables a reduction in the number of dependent variables while preserving a maximum amount of the space-time variance. Basically, a smaller set of data is derived from an original set by removing, through application of statistical techniques, the redundancy inherent in the latter. At Hanford the best results in wind predictions have been obtained by considering the field of pressure and in identifying observed winds with "map types." These relationships were developed objectively, using empirical orthogonal functions.

The first step in developing the method for the Hanford area was to determine which variables were important and to obtain as large a dependent sample as possible. Most importantly, the pressure distribution in space and time had to be specified in a manner that would yield the best correlation with wind velocity p  ible. Problems of grid size, distance between grid points, and relative  eight of grid locations were all factors which were to be accounted for in the model. It was important to keep foremost in mind the fact that a relationship between the velocity and the pressure gradient was to be developed, and that a dynamic relationship should be a guiding influence. The difficulty arose, however, that any realistic dynamic

model involved factors for which there were no available observations, so
it was recognized early that the degree of success of the final prediction
equation was greatly reduced.  In the case at hand, the sparsity of density
and pressure observations in the immediate vicinity of the Hanford Meteoro-
logy Tower was a recognized weakness.  From the evidence available, it
was apparent that the wind was not only affected by the broad-scale pressure
distribution but also by smaller-scale factors.  There were indications that
there were rather large gradients of pressure and density just east of the
Cascades, but there were not sufficient data available for analysis.  Figure
III-4 is a map showing the grid points for which 1600 PST sea-level pressure
was obtained.  The governing criterion for their selection was that an
analysis based on data for 11 grid points should not differ in major detail
from an analysis based on all available information.  The 11 points were
thus selected by trial-and-error so that the data collected from them would
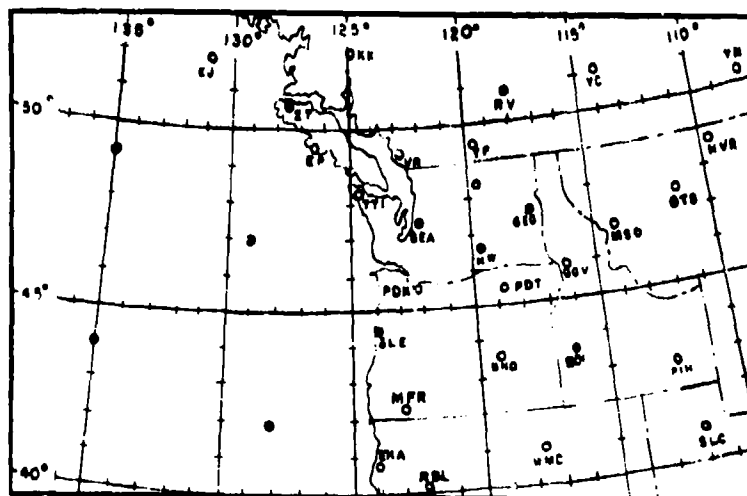be representative of the large-scale pressure pattern.



Figure III-4.  Selected Grid Points From Which Sea-Level
Pressure Data Were Obtained and Subsequently Trans-
formed in Terms of Empirical Orthogonal Functions

The dependent sample was comprised of all the available 1600 PST
sea-level pressure data for the months of July and August for the years
1952-1958. The data were taken exactly as the stations reported, except
for the grid points in the ocean where data were interpolated from the com-
plete analysis. Data for 1954 were not included in the final analysis because
of the large number of missing values. This limited the dependent sample
size to 6 years or 12 summer months.

The data were diagonalized on the 709 digital computer in the manner
described by Shorr.[6] The initial matrix was comprised of the pressure
anomalies for each grid point where the mean values were the average sea-
level pressure for the 2-month period. Each "map" was represented by
11 anomalies. The process of diagonalization transforms the pressure de-
partures, P*, which are characterized by redundancy, into 11 empirical
orthogonal functions, Q*. On the average about 90 percent of the total
space-time variance in the pressure field was represented by a linear
combination of one-third the number of Q's generated. To reverse the
process and reproduce the pressure map, the product of the Q and Y
matrices was found. The constant Y matrix also results from the diagona-
lization. When the Y values, called empirical orthogonal functions of space,
were plotted on a map, the dominant flow characteristics were shown. The
Y values resulting from the diagonalization are given in Table III-3. Shorr[6]
gives a detailed discussion of these variables.

TABLE III-3

Y Values Resulting from Diagonalization

| $Y_1$ | $Y_2$ | $Y_3$ | $Y_4$ | $Y_5$ | $Y_6$ | $Y_7$ | $Y_8$ | $Y_9$ | $Y_{10}$ | $Y_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| .381 | .011 | -.023 | .664 | .201 | .149 | -.215 | -.306 | -.443 | -.035 | -.116 |
| .258 | .254 | .289 | .063 | -.061 | -.228 | -.257 | -.418 | .480 | .102 | .494 |
| .189 | .177 | .513 | -.087 | -.080 | -.372 | .187 | -.079 | -.038 | .246 | -.644 |
| .192 | .300 | -.128 | -.319 | .698 | .100 | .420 | -.238 | .015 | -.153 | .028 |
| .216 | .359 | -.163 | -.198 | -.034 | -.107 | -.537 | .225 | .081 | -.568 | -.280 |
| .213 | .363 | -.259 | -.175 | .057 | -.056 | -.214 | .344 | -.281 | .668 | .171 |
| .232 | .335 | -.455 | .127 | -.590 | .080 | .462 | -.168 | .095 | -.052 | -.063 |
| .231 | .066 | .420 | -.135 | -.214 | -.077 | .239 | .232 | -.515 | -.345 | .448 |
| .401 | -.043 | .243 | .224 | .087 | .472 | .139 | .530 | .439 | .048 | -.046 |
| .447 | -.528 | -.317 | .028 | .111 | -.595 | .118 | .153 | .106 | -.040 | .053 |
| .394 | -.395 | .014 | -.539 | -.210 | .418 | -.196 | -.337 | -.091 | .103 | -.095 |

Having specified the map in relatively few numbers, a linear re-
gression analysis could then be made and a prediction equation for the wind

velocity derived. The first attempt was to relate the components of the 50-ft average hourly tower velocity for specified intervals of time to the Q values obtained by diagonalization. Velocity components were computed for the intervals 2000-2100, 2200-2300, 0000-0100, and 0200-0300 for the days corresponding to Q values, and a regression analysis was made to determine the coefficients in the equations

$$u = A_o + A_1 Q_1 + A_2 Q_2 + A_3 Q_3 + A_4 Q_4, \qquad (4)$$

and

$$v = B_o + B_1 Q_1 + B_2 Q_2 + B_3 Q_3 + B_4 Q_4. \qquad (5)$$

Table III-4 gives the coefficients. The percent reduction in the variance

### TABLE III-4
#### Coefficients of Equations

| Time | $A_o$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | PR |
|------|-------|-------|-------|-------|-------|-----|
| 20-21 | 7.1297 | -0.0008 | -0.0217 | 0.1135 | -0.0019 | 0.41 |
| 22-23 | 8.5121 | 0.0057 | -0.0163 | -0.0741 | 0.0094 | 0.34 |
| 00-01 | 7.3001 | 0.0026 | -0.0124 | -0.0373 | 0.0013 | 0.18 |
| 02-03 | 5.9156 | 0.0016 | -0.0027 | -0.0146 | 0.0021 | 0.03 |

| Time | $B_o$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | PR |
|------|-------|-------|-------|-------|-------|-----|
| 20-21 | -4.1935 | -0.0172 | 0.0264 | -0.0784 | -0.0404 | 0.36 |
| 22-23 | -3.987 | -0.0124 | 0.0130 | -0.0574 | -0.0364 | 0.31 |
| 00-01 | -2.848 | -0.0090 | 0.0150 | -0.0142 | -0.0370 | 0.20 |
| 02-03 | -1.595 | -0.0059 | 0.0068 | 0.0077 | -0.0200 | 0.08 |

is given in the right-hand column. This number was computed by applying the developed equations to the dependent sample; it indicates the goodness of the fit of a straight line through all data points. After 0100 PST, the percent reduction indicate that the climatological mean is as good a value as that predicted by the equations. Actually, in comparison with the accuracy that can be achieved by applying the methods that have been discussed earlier, complete objectivity is the only advantage to be gained in this application.

Later investigations attempted to improve the percent reduction by examining 6-hr pressure change, 24-hr pressure change, 1000 PST temperature field, and linear combinations of these and the 1600 PST pressure field. Results of these investigations were not significantly different from those obtained for the 1600 PST pressure field alone. The conclusion was made that none of these techniques could be used to predict with sufficient accuracy

to be considered useful for the summer operation. Yet, since the number
of variables required to specify any particular field was small, it was con-
venient to examine the functions graphically in search for nonlinear relation-
ships.

An extensive graphical investigation indicated that a complex relation-
ship does exist between u and v and $Q_1$, $Q_2$ and $Q_3$. In the $Q_1 - Q_2$ plane,
velocity component isotachs behave like a damped oscillator with cells of
maximum and minimum appearing in the plane near $Q_3 = 0$. Further,
computations of covariances showed that the variation in velocity can be
mostly accounted for in the variation of $Q_3$ alone. Another complication
was that the relationship varied with time in a complex manner. The results
of this analysis suggested that, for any particular situation, the assumption
that analogous Q's from the dependent sample were associated with analogous
wind and stability was valid. In other words, when the distance between
points $P_1$ ($Q_1$, $Q_2$, $Q_3$) and $P_2$ ($Q_1$, $Q_2$, $Q_3$) was small, the probability was
high that their associated wind, stability, and temporal variations were
similar. Thus it was possible to predict velocities for any situation by
searching the dependent sample for Q values that were similar to those ob-
tained from the current map. Often, two such analogues could be obtained.
The actual predictions will be summarized later in Volume II of this paper.
For each prediction (map) this method was applied in the following manner:
The first three Q's were computed for each sea-level pressure map. Then
the dependent data were searched to determine other sets of Q's representing
past situations which approximated the set derived for the current map.
These were then placed in order headed by that set considered to be "best,"
which was termed the "first analogue," and followed by any other analogues
that were found.

## A PREDICTION EQUATION

During the graphical analysis, it became increasingly evident that the
development of a practical method for prediction must depend on the varia-
tion of $Q_3$. A relatively simple functional relationship that would approach
the degree of success of the subjective techniques was desired. The approach
to obtain these results was strictly empirical, and no defense will be made
at this time for its dynamical inconsistencies.

If any single measurement could be singled out as most importantly
related to the probability of the occurrence of those conditions deemed
favorable for an experiment, it would be the speed of the drainage wind
observed at the station. As previously stated, the peak speed observed in

the summer months occurs on the average between 2100-0200 PST. This
was the onset of the drainage wind, and its measurement for this investiga-
tion was defined in the following way. The NW-SE component of the 50-ft
wind speed was computed for each hour in the period 1600-2400 PST. From
these data, the observation with the highest magnitude was taken as a
measure of the degree of drainage. Positive numbers were associated
with NW to SE components and negative numbers with SE to NW winds.
Since drainage winds were characteristically WNW to NW, this derived
speed differed from the observed speed by only about 2 mph in most in-
stances. Ideal antecedents for stable conditions were fair skies and a
component velocity in the range 7-17 mph. When speeds were 18 mph and
greater, slightly stable conditions occurred almost without exception be-
cause the gusty character of the wind precluded formation of more than a
shallow inversion through the lowest 50 ft above ground. When the observed
component speed was in the interval 1-6 mph, it was improbable that the
plume would travel very far down-course. Furthermore, with these light
wind speeds. the direction was not persistent so that there was considerable
risk that the plume might wander off the course. Negative components never
resulted in favorable wind directions during the period. Wind components
less than 7 mph were not considered to be of the drainage type defined
earlier. The time of occurrence of the average hourly maximum wind is
related to its magnitude. Strong winds ($>$17 mph) arrive early in the evening
near sunset; whereas, in the speed range 7-17, the arrival time is generally
between 2030-2200. Hourly synoptic wind reports and data from the tele-
metering network were also helpful in pinpointing the time.

Where v is the NW-SE component of the highest hourly average speed,
$Q_3$ is an empirical orthogonal function of time, and A is the coefficient, the
equation

$$\ln(v + 5) = A_0 + A_1 Q_3 \qquad (6)$$

is a simple function determined from graphical considerations. The constant,
5, is added to the velocity to eliminate negative numbers from the equation.

Because the velocity appeared to be related to the 24-hr change in $Q_3$,
Eq. (6) was solved for four intervals of change that, in turn, were determined
from graphical considerations. The four intervals were (1) $\Delta Q(24) > 60$,
(2) $0 < \Delta Q(24) < 60$, (3) $-60 < \Delta Q(24)$ 0, and (4) $\Delta Q(24) < -60$. One further
subdivision significantly improved the linear relation for the dependent
sample. In the vicinity of $Q_3 = 0$ in Group (3), high and low values of the

velocity were observed, indicating a region in which $Q_3$ alone could not identify the critical point. By omitting this region from the analysis, the linear correlation was considerably improved at the expense of neglecting a little less than one-quarter of the data. For prediction, if the dependent sample may be used as a guide, the developed equations can be applied objectively about three-fourths of the time, and used with other subjective aids for the remaining one-quarter. Group (3) was then subdivided into

(3A): $\quad \Delta Q(24) \lesssim -40$, $\quad$ (3B): $\Delta Q(24) \geq -20$, and (3C): $-40 < \Delta Q(24) < -20$,

the last group being omitted from the regression analysis. The solution of Eq. (6) for the five areas defined is given in Table III-5 where the computed confidence intervals are at the 95-percent level. A reduction of variance of

TABLE III-5

Solution of Eq. (6) for Five Areas

| Classification | $A_0$ | $A_1$ |
|---|---|---|
| (1) | $2.831 \pm 0.205$ | $0.0082 \pm 0.0035$ |
| (2) | $2.789 \pm 0.061$ | $0.0080 \pm 0.0018$ |
| (3A) | $2.414 \pm 0.617$ | $0.0018 \pm 0.0069$ |
| (3B) | $3.078 \pm 0.321$ | $0.0031 \pm 0.0090$ |
| (4) | $2.762 \pm 0.229$ | $0.0066 \pm 0.0035$ |

71 percent was obtained from the dependent data using all the equations. The value of the method depends on how well the dependent sample represents the population.

For any prediction, there were available numerous surface and upper-air observations which could be subjectively analyzed in the manner of the synoptician, a method which relates the observed pressure gradient to the modal velocity trend over a period of time; an analogue technique; and an objective method for determining the maximum average hourly drainage component in the evening. These considerations led to the final prediction upon which nightly operations were planned. The specific tabulations, along with the observed conditions for each operational night, will be given in a later chapter. Evaluation of these results provides a fair assessment of the worth of these techniques.

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# IV Design of the Diffusion Experiments

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As stated in the introductory chapter of this report, the general objective of the Green Glow experiments was to obtain diffusion measurements in a reasonably dense sampling network over as great a travel distance from the source as possible. The decision was made in the initial planning stages to design the experiments to tie in with the Prairie Grass experiments, a diffusion field study over a distance of 800 m.[1]

This initial decision led to immediate specification of the following design features:

a. Sampling would be done along arcs concentric about the source point.

b. Two of the sampling arcs would be at radial distances of 200 and 800 m.

c. The tracer material would be released from a ground-level source.

In addition, features peculiar to use of the Hanford Fluorescent Tracer System had to be factored into the design. Details of the dispersal, sampling, and sample-assaying techniques appear in Chapters V, VI, and VII, respectively. Design factors peculiar to the tracer system selected were as follows:

d. Maximum release rate for the dispersal equipment was 8 kg per hour.

e. The sample-assaying system was based on counting statistics requiring a minimum of approximately 100 particles per sample.

f. The entire range of the design assaying system was only five orders of magnitude.

g. Centerline dosages on each arc should be at least one hundred times the minimum significant count to provide the required accuracy in arcwise dispersion estimates.

h. The tracer material deposited on the ground surface and vegetation at an unknown rate.

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Consideration of certain practical applications of the results and operational limitations led to the following features:

      i.     Period of emission would be 30 minutes.

      j.     Field samplers would be in operation well before and after the passage of the tracer cloud, thus providing measurements of dosage rather than average concentrations.

      k.     A time history of tracer collection would be attempted at the farther travel distances.

      l.     All of the experiments would be conducted under thermally stable atmospheric conditions, that is, nighttime operations only were planned.

      m.     Samples in the horizontal plane would be collected at a 1.5-m height above the ground.

The major effort of the preliminary design work was directed toward specification of the geometry of the sampling grid, the sampler spacing, and the sampling rates. These specifications had to be consistent with the constraints enumerated in the preceding paragraphs, such that acceptable accuracy could be claimed for the diffusion parameters derived from the measurements. The primary factors considered were:

      a.     Climatological and topographic features of the site.

      b.     Expected lateral and vertical spread of the cloud during extremely stable conditions.

      c.     Limitations of the dispersal and assaying systems.

      d.     Estimated deposition rate of the tracer material.

      e.     Economic and logistical limitations on the number of sampling arcs that could be instrumented and effectively operated.

Before discussing further aspects of the basic design, we should emphasize that the design remained flexible throughout the course of the experiments. Certain design features had to be altered as the work progressed and knowledge was gained of certain problems that were not anticipated. There were two problems in particular that caused some trouble, and these will be discussed later. The point of note at present is that a planned feature of the experiments was a continual qualitative checking of experimental data, as they were obtained, to guard against mistakes or oversights in the over-all design.

Little time was spent considering the use of sticky paper or similar devices to obtain estimates of the rate of deposition of the tracer material. Such devices pose serious data-reduction problems and leave one with the

unenviable task of attempting to relate the results to what he _thinks_ the rate of deposition on natural surfaces is or should be. It was decided instead to instrument a fairly dense vertical grid as well as a horizontal grid in an attempt to arrive at estimates of mean rates of deposition through differences between the mean rate of transfer through a vertical surface and the rate of emission. It was recognized that this approach would have its own particular difficulties in that, ideally, one needs simultaneous continuous records of concentration and wind speed at the grid points in the surface to arrive at the proper space-time integration of transport through the surface. The experimental setup implied by this requirement, however, is obviously a problem worthy of study in itself. In short, the decision to arrive at deposition estimates through vertically measured dosages rather than sticky paper devices represented a compromise of the ideal diffusion-deposition experiment.

Sampling in the vertical was restricted to samplers placed at fixed heights on towers to eliminate problems that are basically logistical in vertical sampling along cables supported by tethered balloons. This restricted the maximum downwind distance at which samples in the vertical could be easily obtained. The final design for the vertical grid utilized 20 towers, five each along arcs with radii of 200, 800, 1600, and 3200 m. The azimuth bearings of the towers, consistent with the site climatology, were set at $08^{\circ}$, $108^{\circ}$, $114^{\circ}$, $122^{\circ}$, and $130^{\circ}$ from the source point for each arc. Fifteen sampler heights were located on each tower, designed to be logarithmically spaced near the ground and arithmetically spaced near the top of the tower. Table IV-1 gives the nominal sampling heights designed for the towers, while Table IV-2 gives the actual sampling heights as measured at the end of the summer's program. Discrepancies between the heights in the two tables arise primarily because of difficulties in defining the ground surface plane from which to measure. The heights in Table IV-2 were obtained by measuring down from the top of the tower to each sampler location on the tower and to the ground. (See Chapter VI for details.)

The towers used were 90-ft poles on the 200-m arc; 140-ft triangular cross-section aluminum towers on the 800-m arc; and 204-ft rectangular cross-section aluminum towers on the 1600- and 3200-m arcs.[4] On the basis of preliminary experiments at Hanford and estimates made from an analysis of Prairie Grass data,[2] it was anticipated that these towers would probably not be high enough to fully bracket the vertical depth of the pigment cloud except for runs made under extreme thermally-stable conditions. However this was accepted as a reasonable compromise with the total cost of

### TABLE IV-1

Design heights (m) for tower samplers
at the four inner sampling arcs

| Sampler | ARCS | | | |
|---|---|---|---|---|
| No. | 200 m | 800 m | 1600 m | 3200 m |
| 15 | 27.0 | 42.0 | 62.0 | 62.0 |
| 14 | 24.3 | 37.8 | 55.8 | 55.8 |
| 13 | 21.6 | 33.6 | 49.6 | 49.6 |
| 12 | 18.9 | 29.4 | 43.4 | 43.4 |
| 11 | 16.2 | 25.2 | 37.2 | 37.2 |
| 10 | 13.5 | 21.0 | 31.0 | 31.0 |
| 9 | 10.8 | 16.8 | 24.8 | 24.8 |
| 8 | 0.45 | 14.7 | 21.7 | 21.7 |
| 7 | 8.1 | 12.6 | 18.6 | 18.6 |
| 6 | 6.75 | 10.5 | 15.5 | 15.5 |
| 5 | 5.4 | 8.4 | 12.4 | 12.4 |
| 4 | 4.05 | 6.3 | 9.3 | 9.3 |
| 3 | 2.7 | 4.2 | 6.2 | 6.2 |
| 2 | 1.35 | 2.1 | 3.1 | 3.1 |
| 1 | 0.675 | 1.05 | 1.55 | 1.55 |

## TABLE IV-2

Heights (m) for tower samplers as measured at end
of field program.  (GS denotes sampler in the
horizontal network at the tower azimuth.)

### 200-m Arc

| Sampler No. | 98° | 106° | 114° | 122° | 130° |
|---|---|---|---|---|---|
| 15 | 26.34 | 26.39 | 26.42 | 26.26 | 26.37 |
| 14 | 24.24 | 24.31 | 24.33 | 24.17 | 24.28 |
| 13 | 21.57 | 21.59 | 21.64 | 21.46 | 21.59 |
| 12 | 18.86 | 18.92 | 18.95 | 18.76 | 18.89 |
| 11 | 16.14 | 16.21 | 16.23 | 16.05 | 16.18 |
| 10 | 13.44 | 13.54 | 13.54 | 13.37 | 13.49 |
| 9 | 10.73 | 10.83 | 10.85 | 10.68 | 10.81 |
| 8 | 9.39 | 9.46 | 9.47 | 9.31 | 9.45 |
| 7 | 8.04 | 8.12 | 8.12 | 7.96 | 8.13 |
| 6 | 6.67 | 6.78 | 6.77 | 6.60 | 6.76 |
| 5 | 5.32 | 5.41 | 5.42 | 5.30 | 5.41 |
| 4 | 3.98 | 4.05 | 4.05 | 3.92 | 4.08 |
| 3 | 2.64 | 2.68 | 2.74 | 2.67 | 2.69 |
| GS | 1.42 | 1.50 | 1.51 | 1.44 | 1.49 |
| 2 | 1.28 | 1.33 | 1.36 | 1.30 | 1.35 |
| 1 | 0.635 | 0.675 | 0.700 | 0.620 | 0.700 |

### 800-m Arc

| Sampler No. | 98° | 106° | 114° | 122° | 130° |
|---|---|---|---|---|---|
| 15 | 41.96 | 41.94 | 42.04 | 42.01 | 42.04 |
| 14 | 37.81 | 37.74 | 37.87 | 37.82 | 37.82 |
| 13 | 33.63 | 33.53 | 33.69 | 33.60 | 33.60 |
| 12 | 29.44 | 29.36 | 29.49 | 29.41 | 29.41 |
| 11 | 25.25 | 25.15 | 25.27 | 25.25 | 25.17 |
| 10 | 21.01 | 20.96 | 21.06 | 21.01 | 21.01 |
| 9 | 16.82 | 16.79 | 16.87 | 16.82 | 16.82 |
| 8 | 14.73 | 14.71 | 14.76 | 14.71 | 14.73 |
| 7 | 12.62 | 12.62 | 12.68 | 12.62 | 12.65 |
| 6 | 10.52 | 10.52 | 10.57 | 10.57 | 10.54 |
| 5 | 8.38 | 8.41 | 8.46 | 8.41 | 8.43 |
| 4 | 6.27 | 6.33 | 6.35 | 6.29 | 6.33 |
| 3 | 4.24 | 4.19 | 4.24 | 4.22 | 4.22 |
| 2 | 2.11 | 2.05 | 2.11 | 2.08 | 2.11 |
| GS | 1.47 | 1.45 | 1.50 | 1.47 | 1.50 |
| 1 | 1.04 | 1.02 | 1.04 | 1.02 | 1.04 |

**TABLE IV-2 (Continued)**

| Sampler No. | 1600-m Arc 98° | 106° | 114° | 122° | 130° | Sampler No. | 3200-m Arc 98° | 106° | 114° | 122° | 130° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 62.43 | 60.70 | 62.54 | 62.49 | 62.37 | 15 | 62.40 | 62.43 | 62.43 | 62.38 | 62.41 |
| 14 | 56.25 | 56.30 | 56.31 | 56.25 | 56.11 | 14 | 56.17 | 56.19 | 56.18 | 56.10 | 56.15 |
| 13 | 50.04 | 50.10 | 50.10 | 50.04 | 49.99 | 13 | 49.98 | 50.02 | 49.92 | 49.97 | 49.98 |
| 12 | 43.84 | 43.85 | 43.89 | 43.82 | 43.82 | 12 | 43.73 | 43.68 | 43.75 | 43.67 | 43.82 |
| 11 | 37.36 | 37.59 | 37.64 | 37.62 | 37.62 | 11 | 37.59 | 37.51 | 37.59 | 37.52 | 37.64 |
| 10 | 31.33 | 31.40 | 31.34 | 31.35 | 31.42 | 10 | 31.35 | 31.35 | 31.35 | 31.32 | 31.32 |
| 9 | 25.09 | 25.20 | 24.98 | 25.15 | 25.22 | 9 | 25.12 | 25.12 | 25.05 | 25.13 | 25.04 |
| 8 | 22.02 | 22.02 | 22.10 | 22.04 | 22.01 | 8 | 21.99 | 21.94 | 21.96 | 22.03 | 21.96 |
| 7 | 18.92 | 18.94 | 18.96 | 18.96 | 28.91 | 7 | 18.90 | 18.89 | 18.89 | 18.95 | 18.94 |
| 6 | 15.83 | 15.89 | 15.95 | 15.89 | 15.88 | 6 | 15.76 | 15.78 | 15.79 | 15.83 | 15.80 |
| 5 | 12.69 | 12.74 | 12.76 | 12.76 | 12.69 | 5 | 12.66 | 12.67 | 12.69 | 12.69 | 12.68 |
| 4 | 9.54 | 9.59 | 9.61 | 9.61 | 9.58 | 4 | 9.53 | 9.52 | 9.56 | 9.57 | 9.56 |
| 3 | 6.45 | 6.50 | 6.50 | 6.46 | 6.79 | 3 | 6.48 | 6.45 | 6.50 | 6.48 | 6.53 |
| 2 | 3.37 | 3.41 | 3.42 | 3.39 | 3.41 | 2 | 3.38 | 3.39 | 3.40 | 3.39 | 3.38 |
| 1 | 1.82 | 1.85 | 1.85 | 1.80 | 1.84 | 1 | 1.82 | 1.82 | 1.85 | 1.82 | 1.82 |
| GS | 1.75 | 1.77 | 1.76 | 1.77 | not measured* | GS not measured* | 1.75 | 1.75 | 1.75 | 1.74 | 1.75 |

*Ground sampler offset from tower location.

tower operation.

In establishing the geometry of the horizontal network, certain theoretical[8] and empirical[7] work was used as a guide in specifying the sampler spacing along any given arc. Briefly the results of the cited studies indicate that, for Gaussian dosage distributions, one requires something between one a. 1 two samplers per standard deviation ($\sigma_y$) of the distribution to adequately describe the distribution. Accordingly expected $\sigma_y$'s were estimated using analyses of Hanford and Prairie Grass data cited above and data collected at the M. I. T. Round Hill Field Station which included information of the variation of $\sigma_y$ with sampling time.[3] On the basis of these estimates, along with a freely admitted safety factor on the side of conservatism, the sampler spacing at the various arcs chosen for instrumentation was established as shown in Table IV-3.

The arc lengths and orientations shown in Table IV-3 were chosen on the basis of the climatology of the surface winds and topography of the site. However the orientation of the inner arcs had to be changed after Run No. 10. The mean surface winds were frequently westerly or even slightly south of west early in the evening and did not switch to northwesterly till later at night. In general the experiments had to be started fairly early in the evening to permit clearance of the tracer cloud beyond the 16-mile arc before breaking of the temperature inversion after dawn. The reorientation of the arcs, applicable from Run No. 11 on, is shown in Table IV-3. The outer two arcs (5 and 6) did not have to be reoriented.

The limited sampling along the 1600-m arc was not planned until just prior to the actual experiments. The equipment necessary to operate this arc was originally planned as reserves to cover possible breakdowns during the summer. At the last moment, the decision was made to gamble on the number of breakdowns that would occur and partially instrument the 1600-m arc. All that was hoped for on this arc was to observe the peak dosages. Consequently no reorientation of this arc was made.

The last line in Table IV-3 indicates the flow rates established for the various sampling distances. These flow rates were designed to offset the occurrence of decreasing concentration with distance, the objective being to obtain measurable dosages at the outer arcs without seriously overloading the inner arcs.

Early in the summer the filters that were exposed on the outer two arcs (flow rates of 4 cfm) were observed to be collecting sufficient dust to partially obscure the tracer particles. The blame for this was first placed on dust that was raised during servicing of the arcs. Servicing roads had been graded

TABLE IV-3

Design specifications of the horizontal sampling network

| Arc No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Arc Radius (m) | 200 | 800 | 1600 | 3200 | 12,800 | 25,600 |
| Arc Radius (miles) | 0.125 | 0.5 | 1 | 2 | 8 | 16 |
| Sampler Spacing (deg) | 2 | 2 | 1 | 1 | 0.5 | 0.25 |
| Arc Length (deg) | 90 | 90 | 48 | 90 | 75 | 37.25 |
| Arc Orientation (deg) (Runs 1 through 10) | 90-180 | 90-180 | 90-138 | 90-180 | 90.0-165.0 | 106.5-143.75 |
| Arc Orientation (deg) (Run No. 11 on) | 68-158 | 70-160 | 90-138 | 71-161 | 90.0-165.0 | 106.5-143.75 |
| Flow Rates (cfm) | 0.267 | 0.267 | 0.54 | 1.08 | 4.0 | 4.0 |

in the desert floor downwind of each arc when the sampling network was being constructed, but only the four inner-arc roads had been oiled prior to the experiments. The main reason for the oiling was to provide a hard surface for the servicing vehicles. There were four-wheel-drive trucks available for the outer arcs that could be driven through the sand without difficulty; and standard rear-wheel-drive trucks were used on the four inner arcs.

The outer two arcs were oiled as expeditiously as possible in hopes that this would eliminate the dust-loading problem. However, oiling alleviated but did not overcome the problem. Several pilot studies conducted during the summer dramatically showed the real cause to be the natural dust load of the air combined with high flow rates and long exposure times at the 8- and 16-mile arcs.

This experience obviously points out an error in the design. Estimates of dust loading in the initial design stages were based on dust samples collected near the Meteorological Tower in conjunction with other studies. None of t' ... ...mples indicated the existance of a serious dust problem. By the time the cause of the dust problem had been identified, it was too late '. change the experimental design. Needless to say, the experience was ...ewed with considerable consternation. However, in a final evaluation, it proved to be a rather fortunate circumstance, for it motivated experimentation with data-reduction techniques that could distinguish between the dust and tracer particles. (See Chapter VII on sample assaying.)

Only one aspect of the design objectives remains to be discussed; namely, the employment of the drum samplers. These were placed at selected points on the outer two arcs to obtain a continual record of tracer collection. The objective was to compare times of arrival and departure of the cloud with the surface mean wind field. On the basis of work reported by the Los Angeles Air Pollution Foundation,[6] it was expected that surface wind trajectories would not be adequate for predicting the times of cloud passage at the outer arcs. The details of this part of the program are reported elsewhere.[5] Briefly, however, the winds in the vicinity of the 100-ft level were found to correlate well with the arrival and departure times indicated by the drum samplers.

## Acknowledgments

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# V  Aerosol Dispensing Technique

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The fluorescent pigment used as a tracer during the Green Glow test was dispensed through two standard Todd Insecticidal Fog Applicators, TIFA, using water as a carrier.

The TIFA (Fig. V-1) is an aerosol fog generator that consists of four primary components: an air blower, which delivers 160 cfm to the atomizer cup, used to atomize the liquid carrier; a combustion chamber, used to heat the air from the blower and aid atomization and evaporation of the carrier; a formulation pump to supply the formulation to the atomizer cup under pressure; and a 7.5 hp gasoline engine to drive the blower and the pump and also to supply a continuous electric spark to fire the combustion chamber.

The dispensing rate was varied by adjusting the formulation pressure or by adjusting the particle size selector or by a combination of both. It was not desirable to generate at large particle size settings since the larger droplets would tend to "rain out," carrying the tracer material to the ground near the generator. Also, operating the dispenser at very low particle size settings would reduce the outlet valve opening sufficiently to cause an uneven dispensing rate at high concentration of pigment in the formulation. The dispenser may be operated either with or without heating the air. Use of heat creates some undesirable thermal effects; however, it promotes evaporation of the carrier liquid and reduces "rain-out." It was determined that a volumetric generation rate of about 20 gph and a blower air temperature of 750°F would produce a spray that essentially evaporates within a few feet after it is emitted. Evaporation of the carrier aids in dissipating the heat so that the effluent from the generation appears dry and cool within 4 to 6 ft from the exit nozzle. Each system will carry about 2 kg of pigment at the generation rate of 20 gph without clogging or causing the generation rate to vary. Optimum generating conditions were assured during the Green Glow tests by utilizing two dispensers placed side by side, with a common formulation tank.

To minimize losses on vegetation close to the source, the nozzles of the two dispensers were pointed upward. The elevation angle on the first
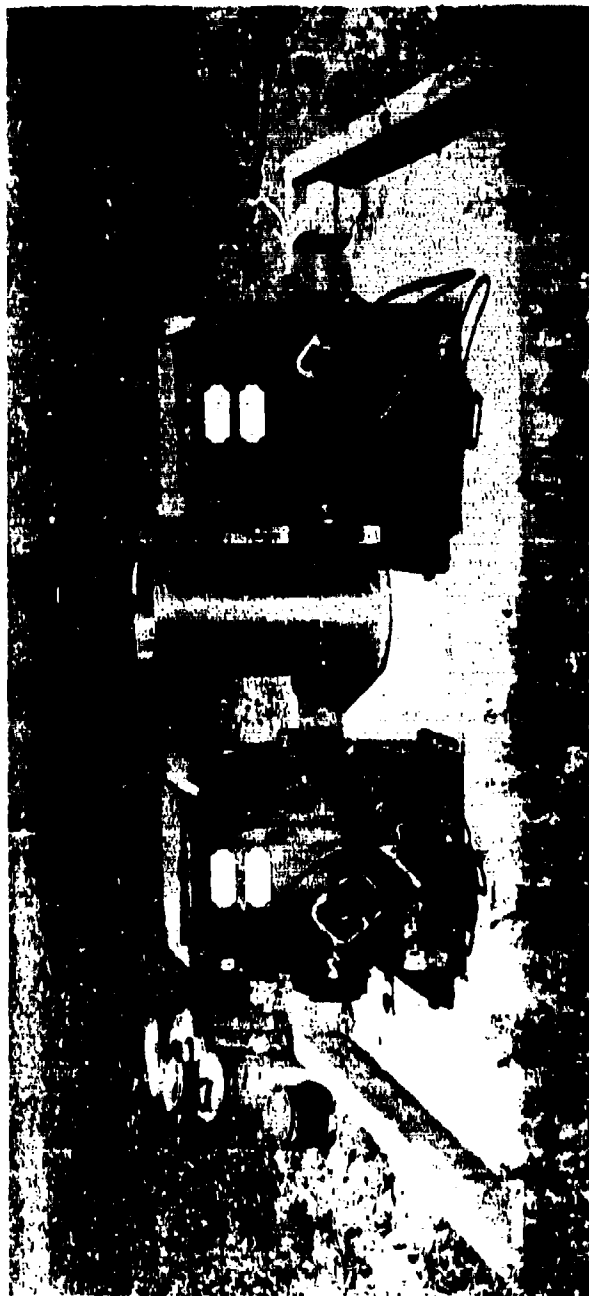
Figure V-1. Todd Insecticidal Fog Applicators, TIFA

four experiments gave an effective plume height of 5 to 6 m above ground. From the fifth experiment on, the elevation angle was lowered to 30°, giving an effective height estimated to be about 2 to 3 m above ground. To simulate a point source, the nozzles of the two dispensers were pointed inward, the axis of each making an angle of 40° with the centerline of the sampling grid.

Variability of the generation rate at a given setting was checked by placing a float, attached to a Leupold Stevens water-level recorder, in a cylindrical container filled with the formulation. TIFA was then started and allowed to run unattended. Figure V-2 shows the time history of liquid consumption that was measured on three different generator settings. The dispensing rate was essentially constant.

The fluorescent pigment used during these tests was zinc sulfide, U.S. Radium Corporation designation No. 2210. To assure a uniform particle-size distribution throughout the test series, all the pigment was prepared as a single batch by the manufacturer and completely blended before packaging.

The formulation was prepared by mixing the pigment with a surface active agent, sodium lauryl sulfate, in the ratio of 2 gm of detergent per 1000 gm of pigment. A small amount of water, about one-half gallon, was added to this and thoroughly mixed until all pigment was wet. It was then transferred to the large formulation tank, where it was mixed for 20 minutes prior to and during generation. A propeller-type industrial mixer was used to mix the first three Green Glow runs. However, for reasons as yet unexplained, the pigment did not appear to be uniformly distributed in the carrier with this type mixer. Consequently this mixer was abandoned and, for the remainder of the runs, the formulation was mixed with two bilge pumps, each having a capacity exceeding 1000 gph. Each dispenser recirculates the formulation at the rate of 200 gph. Therefore, the formulation was circulated at a rate of more than 2400 gph for 20 minutes prior to, and all during, generation. Homogeneity of the formulation was checked by drawing samples directly from the intake line of the dispenser during generation.

The generation rate was set prior to the start of the run and was not altered after generation was started. The actual amount of pigment emitted during each run was computed by subtracting the amount of formulation remaining in the tank at the end of the generation period from the total formulation in the tank at the beginning of the generation period.
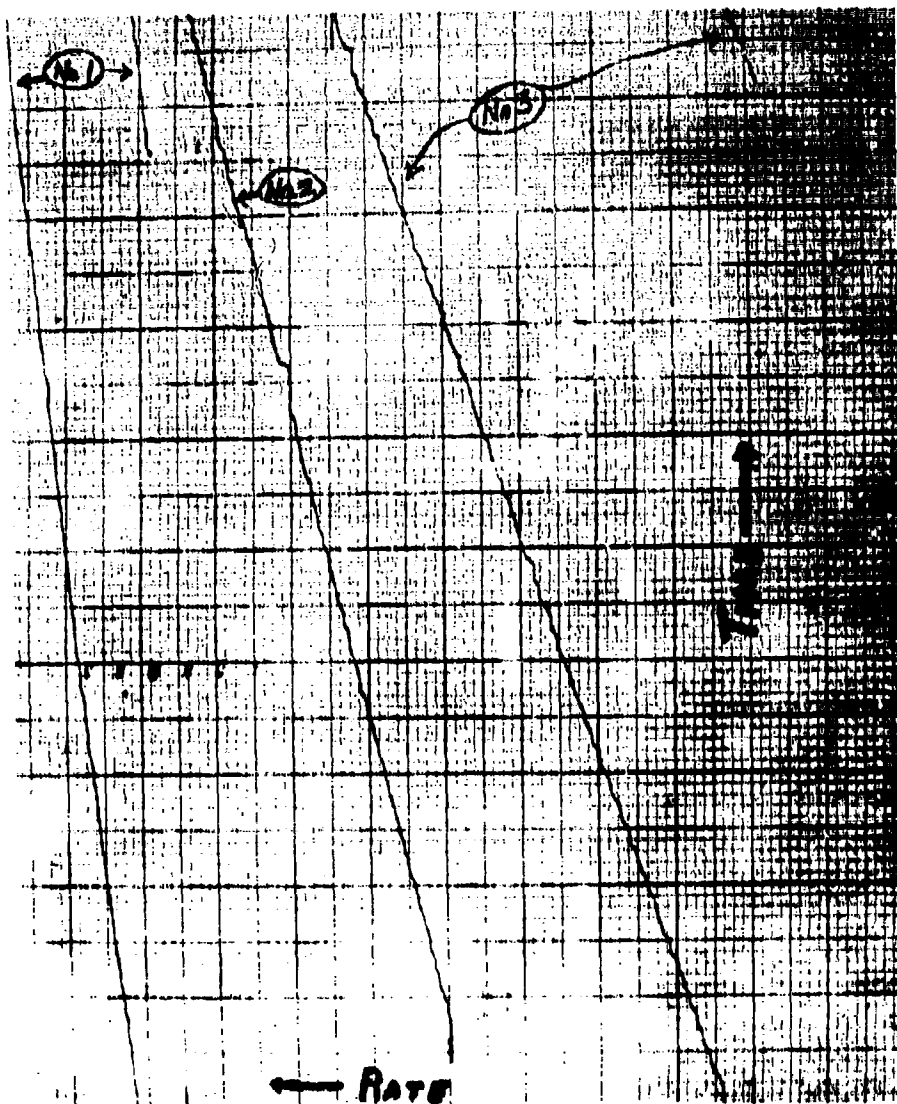
Figure V-2. Time History of Liquid Consumption Measured on
Three Different Generator Settings

# VI  The Field Sampling Grid

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The field sampling grid was completed as near as possible to the specifications derived from design criteria described in Chapter IV. Certain minor changes in the actual grid were required to avoid blocking the roadways, but these were minimal.

Figure VI-1 shows the horizontal sampling grid that is centered at a distance of 100 m due south of the Meteorology Tower to obtain a reasonably unobstructed fetch for the northwesterly winds to be studied. A monument was placed at this point and a base-line surveyed and monumented to a distance of 25,600 m at an azimuth of $135^\circ$. All subsequent grid measurements were referred to the base line. Each arc was carefully surveyed and markers were placed at 100-ft intervals along the arc. Sampler locations were then measured from the marker stakes to an accuracy better than 1 ft in true position.

Steel fence posts, 6 ft in length, were driven at each sampler location to support the filter holders; and a servicing road was graded on what would be the downwind side of the sampling arc.

The basic vacuum system used throughout the grid was assembled on the site and consisted of a Gast-Model 2565V, heavy duty, vane-type vacuum pump driven by a Clinton - Series 290, Model TBA, air-cooled, 4-cycle, 1-cylinder gasoline engine shown in Fig. VI-2. Each unit would provide 5 cfm of air flow at critical flow and would operate for at least 5 hrs without refueling. Because of the low volumetric flow rates required on Arcs 1 through 4, it was possible to manifold up to 12 samplers on the pump by connecting them with 1-inch vacuum hose. On Arcs 5 and 6, almost the full capacity of the unit was required and one vacuum unit per sampler position was installed. A total of 396 units was required to supply vacuum to the entire grid system. In addition spare units were placed at convenient locations along the arcs for use when installed equipment failed. Throughout the course of the Green Glow experiments, less than 1 percent of samples was lost because of equipment failure.

The vertical sampling grid was limited to Arcs 1 through 4 according
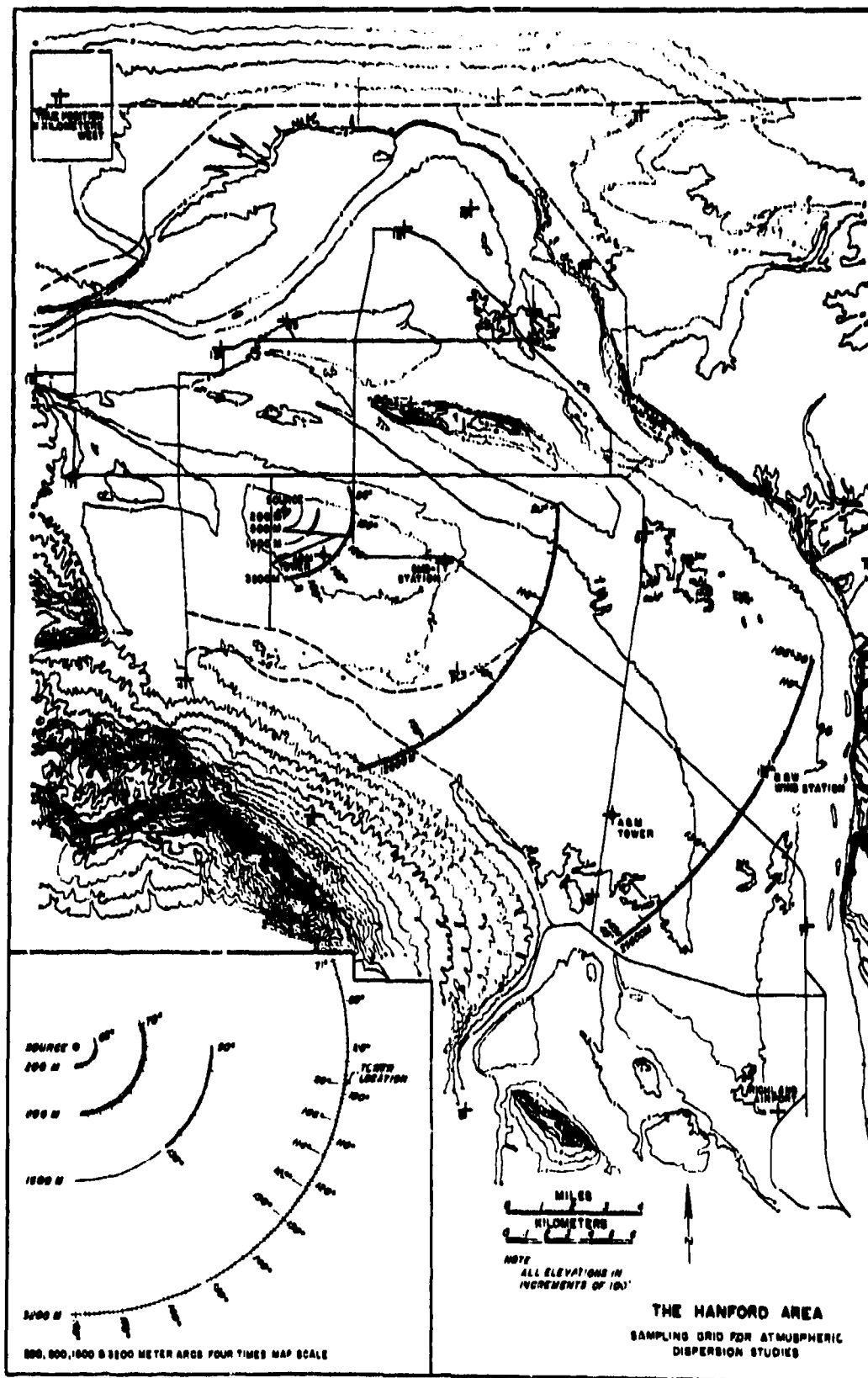
Figure VI-1. Sampling Grid Used in the Green Glow Program

Figure VI-4. Aluminum Tower (AB 216/U
Antenna Support) Shown with Manifold
Hose-Sampler Assemblies



Figure VI-2. Vacuum Pump-and-Engine
Assembly Used at Field Sampler
Locations



Figure VI-3. Sampler-Vacuum Hose
Assembly Shown in Relation to
Garage Door Hangers

to the experimental design. Five vertical sample arrays were supported on each of these arcs by either wooden poles or towers, depending on the height required. The angular spacing of the vertical arrays on each arc was $98^\circ$, $106^\circ$, $114^\circ$, $122^\circ$, and $130^\circ$ azimuth measured from the grid center monument.

The vertical samplers at 200 m distance from the source were supported by 90-ft wooden poles. The samplers were manifolded together and raised as a unit into position on the poles with a rope and pulley system. Orientation of the samplers toward the generation point was maintained by attaching the manifold hose to standard roller garage-door hangers and running them up the pole through tracks as shown in Fig. VI-3.

At the 800-m arc, the vertical samplers were supported by steel towers, 142 ft in height. The samplers were manifolded and raised into position with essentially the same system as used on the 90-ft poles.

Aluminum towers 204 ft in height (AB 216/U Antenna Supports) were used to support the vertical samplers at distances of 1600 and 3200 m from the source (Fig. IV-4). Sampler holders and manifold hose were firmly affixed to these towers, and sample changing was accomplished by climbing the towers.

The air sampled at each location was metered through a critical-flow orifice, and a vacuum of at least 20 inches of mercury was maintained behind each orifice. All orifices on a given arc, in both the horizontal and vertical grids, were calibrated and screened so that no greater than a standard error of 1.5-percent inflow rate could exist along a given arc.

# VII  Description of Sampling and Assaying Procedures

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## BULK FIELD SAMPLES

The primary sampler used in Green Glow was a membrane filter inserted in a disposable polyethylene filter holder. (See Fig. VII-1.) Samples collected on a filter were bulk samples intended to collect all pigment passing through the intake zone during a given run.

Figure VII-1 shows that the sampler unit consists of five parts. The BASE contains a cavity in which a cylindrical roll of creped-paper FILTER BACKING is inserted. A molecular MEMBRANE FILTER* is placed on the plane circular surface formed by the base and the filter backing. The RETAINING RING pinches the periphery of the filter tightly against the base, while the circular area of 1 5/8-inch diameter that is still exposed is supported by the porous creped-paper backing. The DUST CAP merely protects the filter surface both prior to and subsequent to sampler exposure. Vacuum is applied at the ribbed nozzle of the base and the dust cap is removed during field operation. Each filter holder was used only once; thus, there was a complete new set of sampling units for each field test.

The automatic sampling equipment that was used to assay fluorescent pigment on the filters required that the pigment be held on the surface of the filter and not deeply enmeshed in the filtering medium. Gelman AM-1 membrane filters provided a marriage between the requirements of a "hard surface" and a relatively low resistance to flow necessitated by the large volumes of air desired to be sampled at the distant arcs (Arcs 5 and 6). The diameter of particulates completely (99+ %) retained on this filter is less than one micron. In addition, membrane samples are soluble in a variety of solvents; this made possible the development of a process for assaying the pigment in the presence of considerable amounts of dust. The filter assaying procedures will presently be described.

An auxiliary group of samplers was used to obtain estimates of the

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*Membrane Filter, 47 mm diameter, Type AM-1 of Gelman Instrument Co., Chelsea, Michigan

time of first arrival of tracer material on Arcs 5 and 6. These samplers consisted of a clock-driven drum coated with adhesive on which the zinc sulfide was impacted. By observing the time at which the drum started turning, and the degrees of rotation to the first point on the tape at which pigment was impacted, the time of first arrival could be determined. These drum samplers were used only for arrival time estimates in this field test series.

## FIELD SAMPLING PROCEDURES

The location of the 833 field sampling positions has previously been outlined. In normal field procedure, filters to be used in ground samplers during a subsequent field test were dispersed in a plastic sack prior to the current field test. In this way field crew personnel were able to collect the exposed filters after the current test and insert the unexposed (and dust-capped) filter for the subsequent test during one traverse of a field arc. Just prior to the startup of the subsequent test, field personnel had to remove the dust caps from the ground samplers. This was done at the same time the necessary vacuum sources were put in operation.

The exposed field samplers were capped and inserted in the proper position in a wooden box. Each box provided an identified storage position for each of 50 field samplers. The samplers were individually numbered for identification and transported to the data reduction facility located approximately three-fourths of a mile from the pigment release point. This facility was located upwind of the release point to minimize contamination of the exposed filters. Furthermore only persons directly associated with sample analysis were permitted in the laboratory to preclude possible contamination of the area with pigment.

## RANKIN COUNTERS

The bulk samples received from the field were assayed by one of two methods, the method depending on whether or not there was a significant amount of airborne dust collected on the filter.

Filters whose surfaces appeared visually clean were assayed by use of a Rankin counter.[2] This counter utilizes a radioactive isotope as an alpha emitter for activating the fluorescent pigment deposited on the membrane filter. Figures VII-2 and -3 are photographs of the instrument.

In the opened assembly (Fig. VII-3), one can see that 12 complete filter-holder assemblies can be inserted in the turntable of the counting pig. The only processing that has to be done to a field filter before inserting
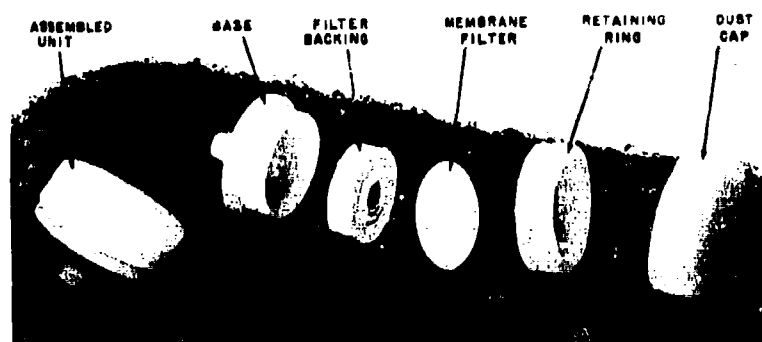
Figure VII-1. Exploded View of Sampler Unit
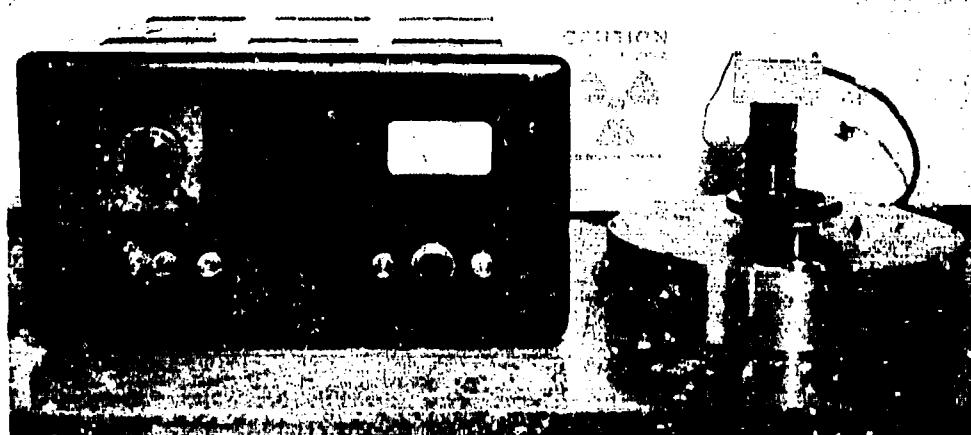


Figure VII-2. Rankin Counter with Associated Scaler
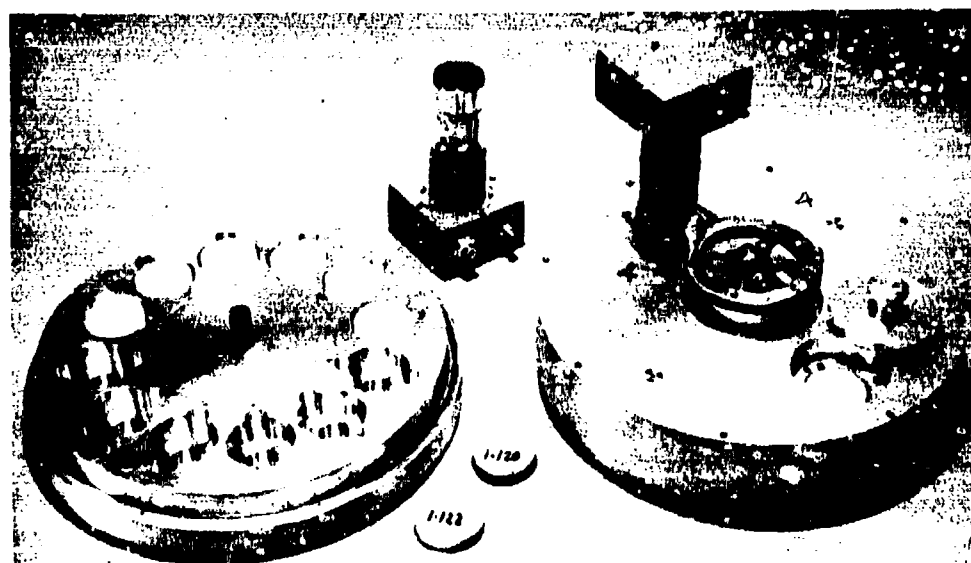


Figure VII-3. Rankin Counter with top removed, shown on the left.

it in the counter is to remove the dust cap. The filter is then rotated to the counting position directly under a Dumont 6292 multiplier phototube. Here, a 200-microcurie plutonium source, in the shape of an annulus about the base of the phototube, bombards the zinc sulfide with alpha particles. The resulting scintillations are viewed by the phototube, amplified, and counted. A scaler high-voltage supply amplifier* is used with the Rankin counter.

Design of the counting pig permits the assayers to insert and remove filters from the turntable at the same time a filter is being counted under the phototube. This procedure resulted in a considerable savings of time in view of the large number of filters being assayed during Green Glow.

Background counts on the two Rankin counters used during Green Glow were numerically low. Overnight background counts made during the Summer of 1959 ranged from two to eight counts per minute.

Normal counting time was 1 minute for field filters with relatively large amounts of pigment. Also, filters whose count was not greatly above background were monitored for only one minute because the counting time necessary to obtain a narrow confidence interval on each filter would have been impracticably long. However there was a "grey" zone in which it was felt the increased confidence in final mass estimate would make a longer count worthwhile. Thus if the count at the end of 1 minute was less than 15 or more than 550, the 1-minute count was accepted. If the 1-minute count fell in the 15 to 550 range, the filter was counted for a total of 3 minutes, and thereby the variance of the count rate was reduced to one-third the 1-minute variance.

Count reproducibility with the Rankin counter was good. Since the actual count to mass calibration was not far from linear, the same statement can be made regarding mass indicated for repeat assays of a given filter. Table VII-1 gives values of $\sigma_x/\bar{x}$ for various count (and mass) values for the Rankin counters used during Green Glow. The $\sigma_x$ is the standard deviation on repeat counts of a given filter, and $\bar{x}$ is the mean count.

### TRI-CARB COUNTING

In some cases filters with the higher flow rates were contaminated with atmospheric dust and/or (less frequently) sampler engine exhaust. The Rankin counters were found unable to accurately indicate the mass of pigment on such filters. If any foreign matter happened to be impacted on top of the fluorescent pigment already on a filter, the resulting Rankin count

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*Radiation Instrument Development Laboratories' Model 49-54

## TABLE VII-1

### Values of $\sigma_x/\bar{x}$ for various count
### values for the Rankin counters

| | Rankin Counter 1 | | Rankin Counter 3 | |
|---|---|---|---|---|
| Count | Mass (gm) | $\sigma_x/\bar{x}$ | Mass (gm) | $\sigma_x/\bar{x}$ |
| 100 | $3.7 \times 10^{-8}$ | 0.082 | $6.6 \times 10^{-8}$ | 0.16 |
| 1,000 | $3.5 \times 10^{-7}$ | .026 | $5.9 \times 10^{-7}$ | .048 |
| 10,000 | $3.3 \times 10^{-6}$ | .008 | $5.3 \times 10^{-6}$ | .038 |
| 100,000 | $3.1 \times 10^{-5}$ | .004 | $4.8 \times 10^{-5}$ | .012 |
| 1,000,000 | $2.9 \times 10^{-4}$ | 0.003 | $4.4 \times 10^{-4}$ | 0.011 |

was lowered for two reasons: (1) the activating alpha particles could not penetrate as easily to the pigment; and (2), even if activated, the scintillations seen by the phototube could be attenuated by the foreign matter.

A correction factor based on the discoloration of the filter surface might possibly have been determined experimentally if it could have been assumed that the pigment and other contaminants were deposited as a homogeneous mixture. However there was no way to assure such homogeneity. For example all the pigment could have been deposited before the dust arrived or vice versa.

The solution to this problem came by placing the "dirty" filter in a two-dram vial and then dissolving the filter in a solvent of three parts ethyl acetate and one part ethyl alcohol.[1] The fluorescent pigment was insoluble in the filter solvent, as were nearly all of the other airborne contaminants. The sample vials were then capped and agitated for about 45 minutes on a wrist-action laboratory shaker to assure complete dissolving of the membrane filter. The vials now contained a homogeneous suspension of pigment and contaminants. The vials were next inserted in a colorimeter*, and the resultant optical density was recorded. Because of the homogeneous nature of the pigment-dirt suspension, calibration for the attenuating effect of the contaminants was possible.

After removal from the colorimeter, each vial was stored momentarily on a magnetic stirrer, and the pigment and dust remained in suspension. (A small metallic stirring rod had been added before the capping of the vial.) Each vial, in turn, was then placed on the elevator of the

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*Klett-Summerson Colorimeter No. 800-3.

shield of a "Tri-Carb" liquid scintillation spectrometer* as shown in Fig. VII-4. Here the vial was irradiated for 5 sec by two encircling 22-watt fluorescent lamps. (Any increase of the time of irradiation over the normal 5 sec resulted in a negligible increase in phosphorescence intensity.) After a 6-sec interval, during which the irradiated vial was being lowered into the counting chamber, an 10-sec count of the phosphorescence (afterglow) of the sample began. The detector was a 2-inch Dumont 6292 multiplier phototube. The count was displayed and recorded, and the elevator automatically ejected the vial. To obtain a low background counting level, the detector system was placed in a deepfreeze.

The maximum count that the Tri-Carb could accurately handle during the normal 18-second counting interval was about 300,000. This counting rate corresponds to a mass of about $10^5$ g of pigment 2210. If the mass of pigment in a vial exceeded this amount, the interval between irradiation of the vial and the initiation of the count had to be extended to a timed interval longer than the normal 6 sec. The decay in phosphorescence would bring the counting rate within the limits of the instrumentation.

## PREPARATION OF TRI-CARB CALIBRATION SAMPLES

To calibrate Tri-Carb counts in terms of mass, several small masses of the ZnS tracer were weighed. The amounts varied from about 0.0004 g to about 0.5 g. To each weighed pigment sample was added a relatively large volume of the acetate-alcohol solvent. Volumes here varied from approximately 500 ml to 3000 ml. From these parent suspensions, volumes of from 0.025 ml to 8.0 ml were transferred by use of a pipette into the two-dram counting vials. A stirring rod and a blank membrane filter were added to each vial and the vials were agitated to assure dissolving of the filter and suspension of the pigment. Duplicate pipettings were made for each volume.

The reason for using such large volumes of solvent in preparing the parent sample from which the daughter samples were pipetted was that first calibration attempts disclosed that pipetting from small volumes of highly concentrated suspensions of the ZnS gave spurious samples.

Inasmuch as a mass of calibration over about six orders of magnitude was desired and the range of volume from the smallest pipetted volume (0.025 ml) to the largest (8.0 ml) was less than three orders of magnitude, it was necessary to prepare more than one parent suspension. The range

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*Tri-Carb Model 314X, Packard Instrument Co., Le Grange, Ill.
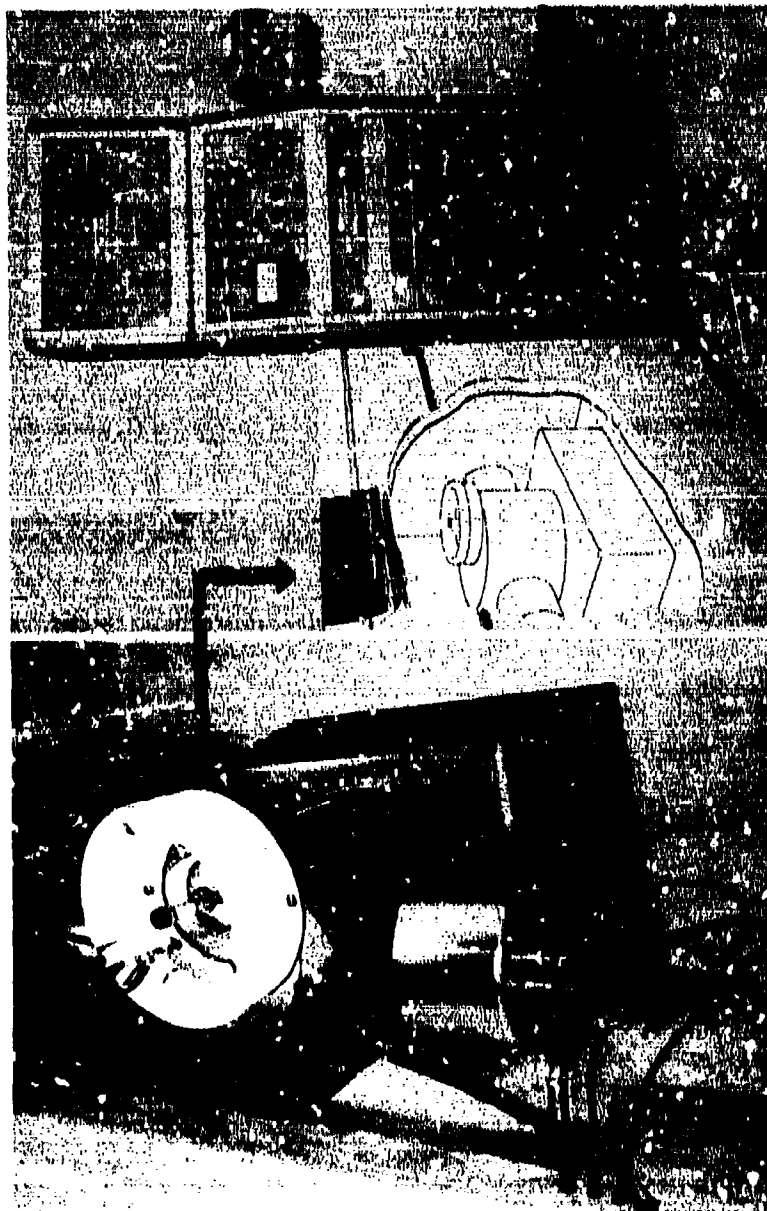
Figure VII-4. Tri-Carb Liquid Scintillation Spectrometer Counting Chamber with Sample on Elevator

of masses pipetted from each parent suspension was made to overlap the series of samples pipetted from the previous parent concentration. The scheme of calibration sample preparation is diagrammed on Fig. VII-5.

Each calibration sample was counted three times in the determination. of the mass vs Tri-Carb count (per 18 sec). The range of calibration for mass extended from about $5 \times 10^{-9}$ g to $2 \times 10^{-3}$ g.

## CALIBRATION OF DUST EFFECT

Once having determined the Tri-Carb count to mass relationship with clean filters, it was necessary to determine the effect on the Tri-Carb counting rate of dust and other foreign matter unavoidably collected with the pigment. One hundred and thirteen filters that had been collected under field conditions, and which had varying masses of pigment, were dissolved and then counted twice each in the Tri-Carb. These filters were purposely chosen so as to be dust free.

To each of the vials was then added a filter that had been collected under field conditions and which displayed some amount of dust, but contained no pigment. The vials were then recounted twice to note the attenuated counts due to the foreign matter. A ratio of the true mass (from original counts) to the apparent mass (from attenuated counts) was then determined.

The dirty vials were inserted in the colorimeter and the turbidity was recorded. Thus the information was at hand to examine the relationship of $Mass_{true}/Mass_{apparent}$ vs colorimeter scale reading.

## CALIBRATION OF RANKIN COUNTERS

The 113 dust-free filters described above had been counted in each of the two Rankin counters previous to being dissolved and counted in the Tri-Carb. Since the Tri-Carb-to-mass relationship was known, the Rankin-to-mass relationship could then be ascertained through the Tri-Carb calibration.
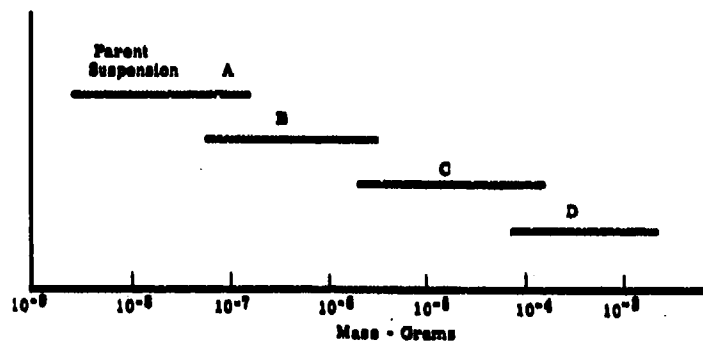
Figure VII-5. Scheme of Calibration Sample Preparation

## References

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# VIII  The Meteorology Tower

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Hanford Laboratories
General Electric Company

One of the outstanding meteorological data collecting facilities at Hanford is a fully instrumented tower 410 ft in height. (See Fig. VIII-1.) It is an open steel-frame construction of triangular cross section, 13 ft on a side. The meteorological instruments are mounted on retractable booms, placed at 50-ft increments on the northwest leg of the tower.

Table VIII-1 shows the heights at which air temperature, dew point, wind direction, and wind speed are measured.

### TABLE VIII-1
Locations of Measuring Elements
on the Meteorological Tower

| Element | Height Above Grade (ft) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 3 | 7 | 50 | 100 | 150 | 200 | 250 | 300 | 400 |
| Temperature | X | | X | X | X | X | X | X | X |
| Dew Point | X | | X | X | | X | | X | X |
| Wind Direction | | X | X | X | X | X | X | X | X |
| Wind Speed | | X | X | X | X | X | X | X | X |

The instruments at heights of 3 ft and 7 ft are located near the tower although they are not physically a part of it.

Air temperatures are measured with aspirated copper thermohms suspended inside a radiation shield. The resistance measurements are made with a 12-point Speedomax strip-chart recorder, providing a complete cycle of the tower elements each 4 minutes. Accuracy is approximately 0.1°F.

Dew-point temperatures are measured with Foxboro Dew Cells suspended inside aspirated radiation shields identical to those for the temperature elements. Dew-point temperatures are recorded on a 12-point Speedomax strip-chart recorder providing a complete cycle of the tower and two reference points each 4 minutes. Accuracy is approximately 0.1°F.

Wind speed and direction are measured with Friez Aerovanes and are recorded on Bendix-Friez strip-chart recorders. These recorders normally

58
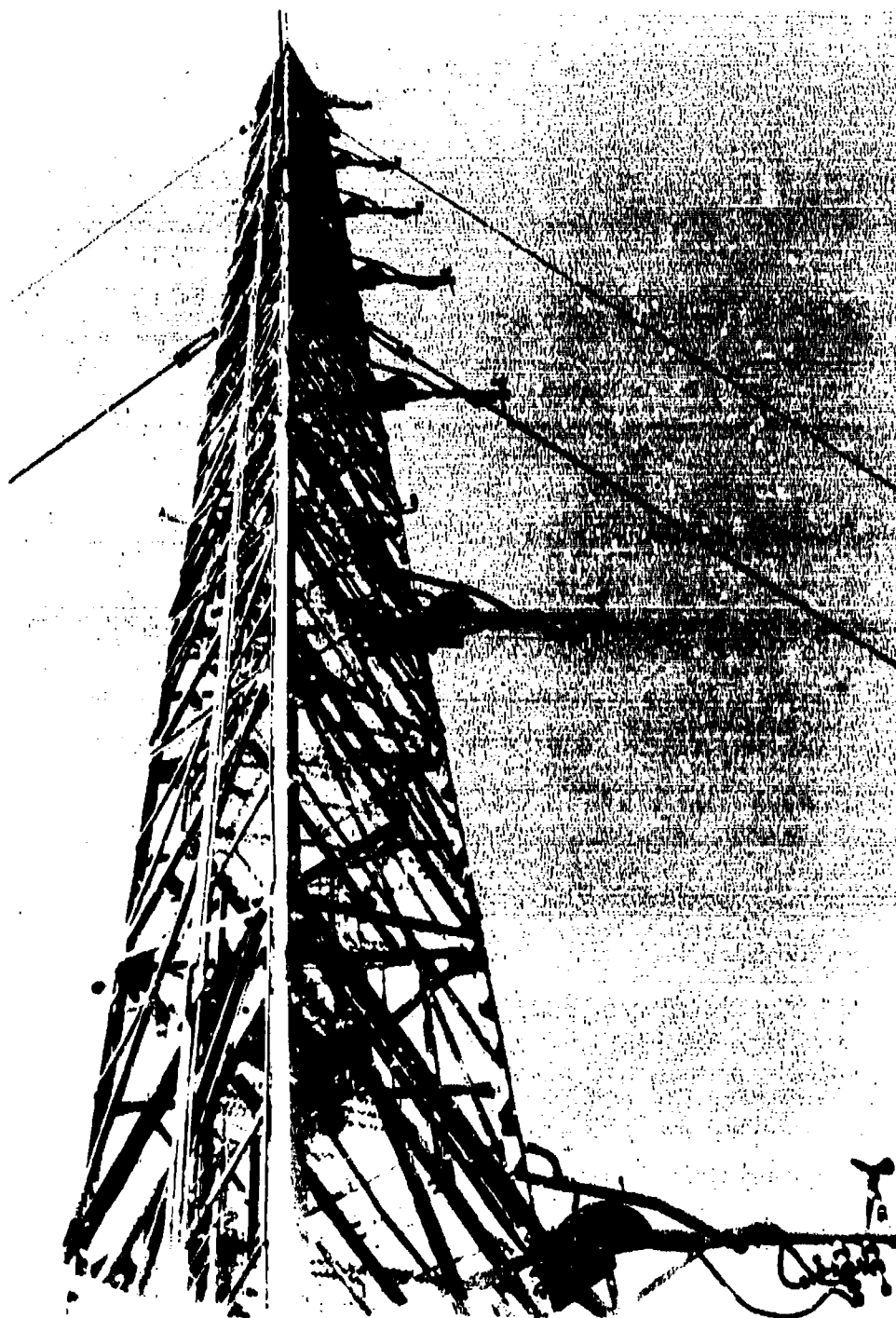


Figure VIII-1.   View of Hanford Meteorology Tower and
                 Instrumentation Booms

operate with a chart travel speed of 3 in./hr. During portions of the
experimental periods, the chart travel speed was increased to 3 in./min.

The weather station, in which the recorders for the tower instruments
are housed, is located approximately 50 ft south-southwest of the tower.

# IX  The Portable Meteorological Mast

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Hanford Laboratories
General Electric Company

## GENERAL

To provide a more detailed profile of temperature and wind than was provided by the 410-ft meteorology tower, a portable meteorological mast was used. Figure IX-1 shows this mast, which is a micrometeorological tool of the General Electric Company's Atmospheric Physics Operation. The mast is a 78-ft tall aluminum structure, triangular in cross section, and is assembled from basic units which are 6 ft high by 29 inches wide.

Figure IX-2 shows that the sensors were mounted on horizontal booms that protrude about 3 ft from the mast. Six of these booms were utilized and were oriented perpendicular to the centerline of the tracer sampling course to optimize exposure during field tests. Figure IX-3 diagrams the approximate vertical distribution of the four wind vanes, six anemometers, and six thermocouples used with the mast.

Briefly, the mast functioned as follows: Signals from the various sensors were telemetered individually to a weatherproof cabinet near the base of the mast. Here, a stepping relay sequentially relayed the signals to a single Leeds and Northrup recording potentiometer that was located in the meteorology building about 350 ft away. Signals recorded on the single strip chart were then manually noted in terms of arbitrary chart scale units. These units were cardpunched and fed to an IBM 703 computer that had been programmed with calibration data for the various sensors. The data processing machine spewed forth the temperature and wind information embodied in this report.

## WIND DIRECTION

Wind direction was determined by the use of Beckman and Whitley wind-direction indicators. The indicator consisted basically of a light-weight vane whose shaft is connected to a low torque potentiometer, which is linear to within 0.5 percent. As diagrammed in Fig. IX-4, the variation of vane potentiometer positioning is directly reflected in the direct-current
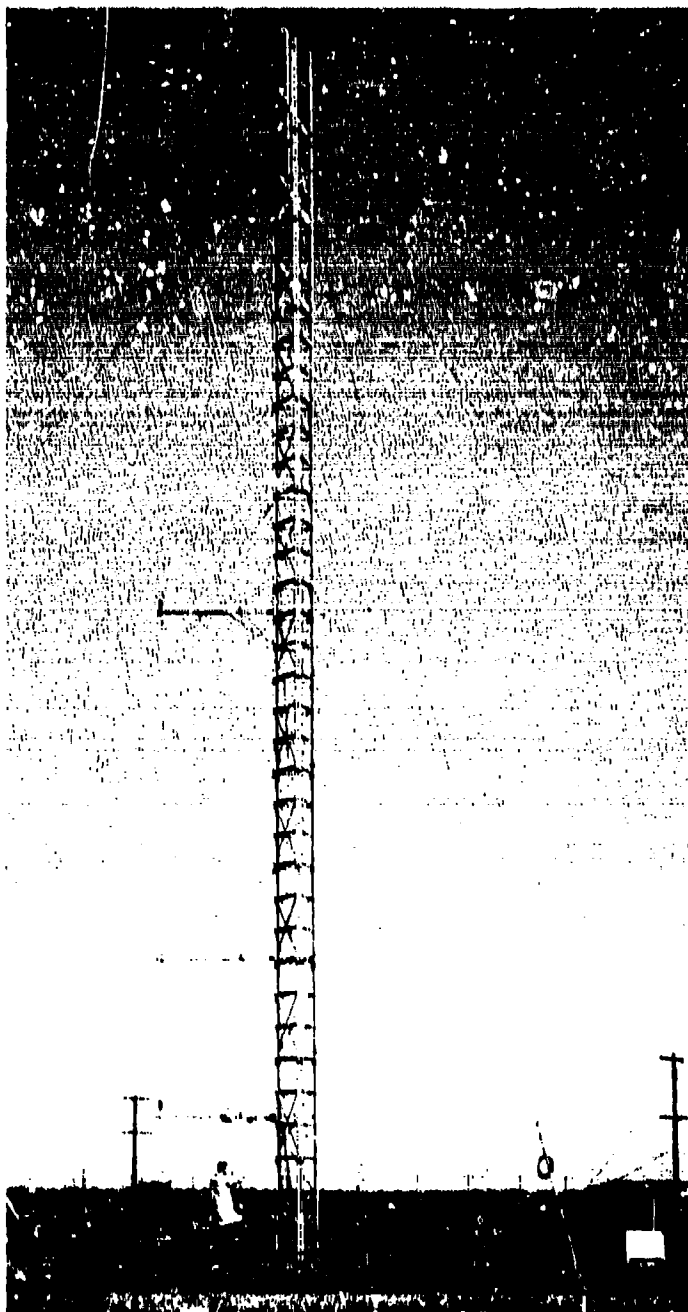
Figure IX-1. Portable Meteorological Mast
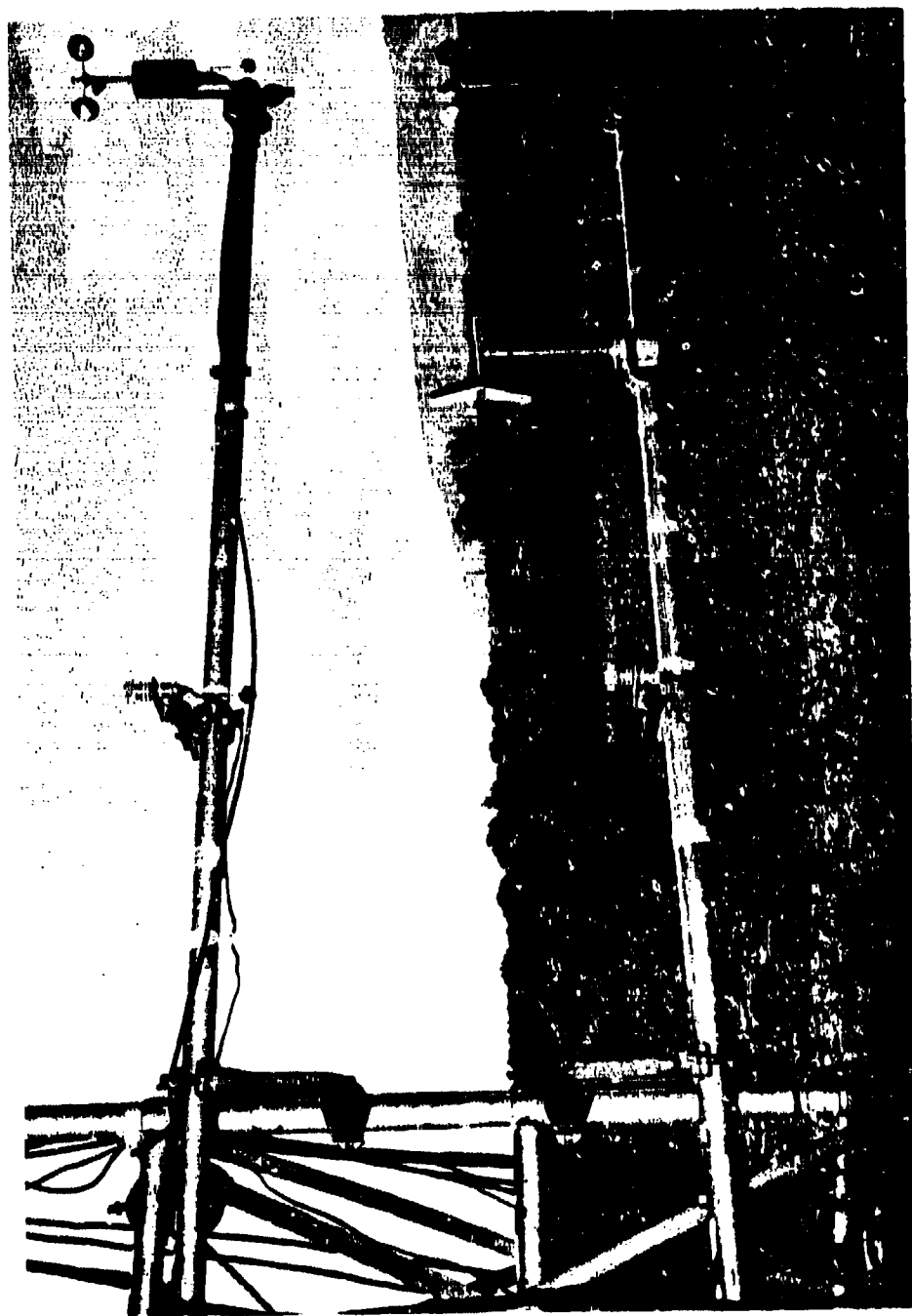
Figure IX-2. Mast Booms and Sensors
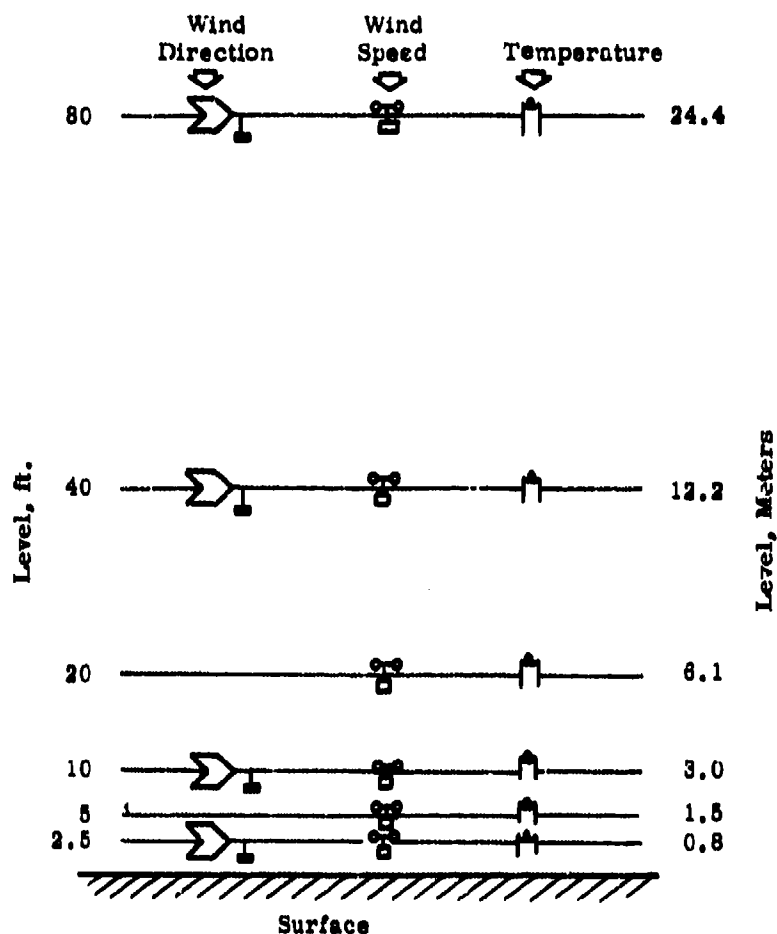
Figure IX-3.  Vertical Distribution of Sensors on a Portable Mast
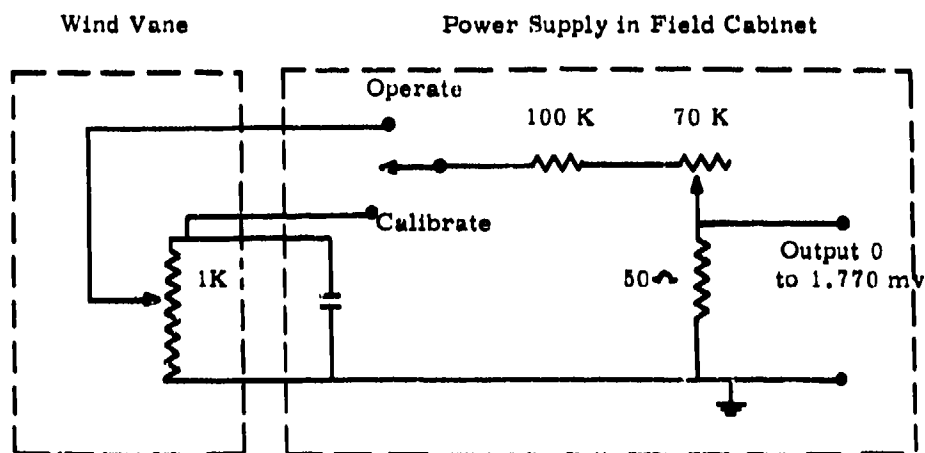


Figure IX-4.  Wind-Vane Circuit Program

voltage that is bled off as output. To allow for varying power-supply voltage (a 6-v dry cell), the 70 K variable resistor is adjustable to give a full-scale output when the operate-calibrate switch is in the "calibrate" position. Such a calibration was made prior to each field run.

## WIND SPEED

Wind speed was monitored by low-torque anemometers manufactured by C. F. Casella and Company, Ltd. These 3-cup anemometers were modified* from their normal totalizing function by removing their geared indicators and drilling a small hole in the anemometer shaft. Electrical pulses were generated when the rotating shaft interrupted the optical path of a light source directed at a cadmium sulfide photocell. These anemometers in their modified form were calibrated from starting speeds of less than 0.8 mph to more than 50 mph.

The electrical pulses of the anemometer were fed to a counting rate meter to permit a direct-current output for telemetering to the recording potentiometer. Figure IX-5 shows a circuit diagram for the anemometer counting rate meter and power supply. The counting rate meter is housed in a weatherproof field cabinet.

To insure proper calibration of the counting rate meter, known pulse frequencies were telemetered to the input of the meter prior to each field run, and associated scale readings of the recording potentiometer were noted. Since the pulse frequency to wind-speed relationship for the anemometers had previously been determined in a wind tunnel, the conversion from wind-speed to recorder scale reading was possible. This relationship was very nearly linear.

## TEMPERATURE

Copper and constantan wires 0.005-inch in diameter formed the thermocouple junction used in the measurement of air temperature. These 5-mil diameter wires were suspended from the tips of heavier gaged copper and constantan needles. The needles were 6 inches in length and spaced about 1/2-inch apart. Thermocouple lead wires from each tower level ran to a common reference junction in the field cabinet, and the thermocouple outputs were sequentially monitored as diagrammed in Fig. IX-6. The signals were telemetered directly to the recorder without amplification.

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*Test, L. D., "An Improved Recording Anemometer System," HW43127 (1956).

ANEMOMETER AND COUNTING RATE METER - CIRCUIT DIAGRAM

ANEMOMETER POWER
SUPPLY CIRCUIT DIAGRAM

Figure IX-5. Anemometer Power-Supply Circuit Diagram
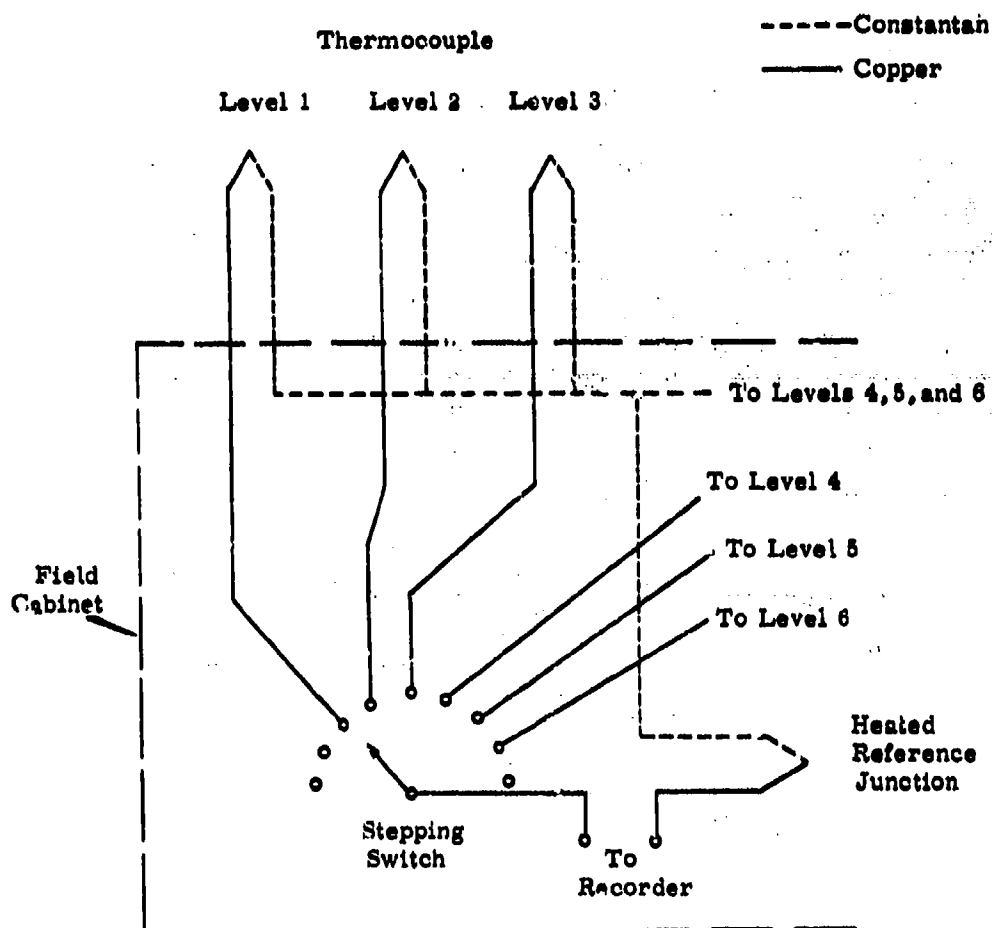
Figure IX-6. Temperature-Monitoring System

The reference junction was housed in the thermally-insulated well of an electrically-heated bath that was manufactured by Sunvic Controls of London. This bath maintained the reference junction at a temperature of 124.4°F with a stability of ± 0.2F°.

The 5-mil thermal junctions were neither aspirated nor shielded from radiation effects. They were occasionally dipped in concentrated nitric acid (and then rinsed thoroughly) in order to maintain their polished and, hence, more reflective surface. Tests have been undertaken in which the thermocouples were alternately exposed to a radiation of about 2 gm calories/cm$^2$-min and then shaded from this radiation. This radiation is greater than the mean solar and sky radiation received at Hanford over <u>any</u> 1-minute period. With a wind of less than 3 mph and the specified high radiation, the indicated temperature difference (the error) was about 0.5F°. With higher winds, the error should decrease.

## DATA SCANNING.

Since there were signals from 16 detectors to be recorded on a single strip-chart recorder, it was necessary to monitor each signal in turn. A scanning unit manufactured by Pannelit, Inc., was used for this purpose.

This scanning unit was located in the field cabinet. It included a 25-point master stepping relay of four banks with goldplated contacts, and a patch panel to which the input signals from the various detectors were brought. From this panel the output of each bank was available to couple the signal from the detector being monitored to the recorder. During Green Glow, only two banks of the relay were used to furnish the signals to the recorder. The stepping interval—variable from 4.0 sec to 0.2 sec—was controlled at the meteorology building, about 350 ft from the field cabinet. The stepping interval was nearly always set at 4 sec.

Since the scanner had a 25-point stepping relay, and detectors required only 16 of the available contacts, 9 contacts were available for other signals. During Green Glow these channels were either open or supplied with constant "locator" signals to facilitate the reading of the strip chart.

## RECORDING AND DATA REDUCTION

The recorder was a Leeds and Northrup Speedomax Slidewire Type G with a special low-level amplifier. The recorder has a full-scale response of less than 1 sec, a sensitivity of 1 microvolt, and an accuracy of 6 microvolts.

The chart, which moved at a rate of 3 in. /hr, was linearly graduated into 100 units. The single pen drew a trace (similar to a bar graph) as the different sensors and "locators" were monitored. The signals associated with wind and temperature sensors were later manually noted in arbitrary scale units on a form from which IBM cards were punched.

The cards—along with cards specifying such information as field test number, time of run, and sensor calibration information—were fed through an IBM 703 computer. The computer was programmed to print directly the monitored meteorological parameters.

# X  Hanford Radio-Telemetering Network

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General Electric Company

In addition to the Tower data, wind direction and speed data for Green Glow were collected from an array of 18 remote radio-telemetering stations in and about the area in which the experimentation took place. Wind directions (16-point compass) and total miles of wind were available for any period of five minutes or more, enabling the data to be applied directly to the estimation of plume trajectories in the operational phase and the analysis of the wind field in the ultimate research. The locations of the 18 remote stations are shown in Fig. VI-1 (page 44). The central receiving station, which collected all the information and converted it directly into numerical code, is located at the Hanford Meteorology Tower, in the proximity of the generation point. In addition a relay station atop Rattlesnake Mountain (8 miles SW of the Tower) served as the transmitter between central station and all remote stations. Before describing the sequence of events observed during the actual operation of the equipment, the physical characteristics of a typical station will be discussed.

The radio-telemetering station is a remote installation (Fig. X-1) that measures wind direction and speed and, upon command, transmits this information to a central station through the relay station. Components of the remote station are: a wind-powered generator and tower, a mast which supports a wind vane and anemometer, a reflector antenna, a battery box containing the battery, a voltage regulator, and an instrument enclosure that houses the electronics chassis. Wind velocity was measured by a modified Bendix-Friez "Aerovane" at a height of 23 ft above the base of the supporting mast.

Figure X-2 shows the receiver and teletypewriter. The typewriter is also equipped with an automatic tape-punching device, allowing records to be preserved in several forms. The receiver has automatic settings, making it possible to call in all the remote stations at intervals of 5 minutes, 15 minutes, 30 minutes, or 1 hour. There is also a control panel for a manual demand of any station at any time.

Operation of the system may be entirely automatic. When the remote

Figure X-2. Receiver and Teletypewriter at the Central Station



Figure X-1. A Typical Radio-telemetering Station Which Transmits Wind Direction and Speed to a Central Station

station is not transmitting, its receiver is in a standby position while the direction and speed at that station are integrating over the period since it last reported. A call tone of a specified frequency is sent from the central station to the relay station, which in turn transmits it to the remote station. When the station "accepts" the signal, a relay is tripped, which places the unit in the position to transmit. It then sends the integrated data with a radio-frequency signal back to the central station by way of the relay station. The signal then is converted to numerical code, and a print-out is made with the station identification. After the message is completed, the stored information at the remote station is canceled and the unit returns to the receive position. A technical description of this operation and the system itself is given by G. E. Driver*.

The reliability of the data received at the central station can be readily assessed since signals are also sent to give measures of the battery voltage and instrument calibration.

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*Driver, G. E., "Instruction Manual Radio-Telemetering Network Data Station," HW 63467 (1960).

# XI  Rawinsonde Observations

Donald W. Stevens
Geophysics Research Directorate

Rawinsonde observations at Green Glow were made by a team of the
6th Weather Squadron (Mobile), Tinker AFB, Oklahoma.  Equipment used
was the AN/GMD-1A and standard Air Weather Service radiosondes*.
Balloons used were ML-391B's, inflated to provide free lift of approximately
350 grams.  This was done in order to attempt an ascension rate of about
500 fpm; however the attempt was not very successful because most ascen-
sion rates were 900 to 1000 fpm.

Computations of data from the recorder records were made by the
6th Weather Squadron personnel in accordance with standard AWS procedures.
These personnel also carefully checked all computations.

For most runs, the wind recorder of the GMD-1A was set to print
angles every 6 sec; however, only the 1-minute values were used in pre-
paring the data which will appear in Volume II of this report.  All original
records are on file at the Geophysics Research Directorate and are
available to anyone interested in examining them.

The schedule of rawinsonde operations called for an ascent one hour
in advance of the expected pigment release, another at the time the fog
generators were started, and a third ascent one hour later.  Departures from
this schedule occurred occasionally because of equipment malfunctions,
unforeseen delays in releasing the pigment, etc.

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*The location of the GMD-1A is shown in Fig. /1-1, page 44.

# XII Operating Procedures for Diffusion Tests

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Hanford Laboratories
General Electric Company

Directing the activities associated with a field test on the scale of the Green Glow experiments required careful integration of the efforts of many people. Communication to the many scattered locations was accomplished by either short-wave radio or telephone service. Since the meteorological conditions chosen for study occurred primarily at night, careful attention was given to providing adequate lighting for safe and efficient working conditions, including spotlights on all mobile equipment.

Test plans specified completing three experiments per week. From the climatological study, test personnel knew that the nocturnal inversions chosen for study would recur nightly for a period of several days and then, perhaps, be unsuitable for experimentation for several days. Therefore every effort was made to complete experiments in as rapid a sequence as possible during favorable periods.

The entire operation was divided into functional components for identification and scheduling purposes as follows:

1. Control Point Operation
2. Texas A and M Tower Operation
3. Rawinsonde Operation
4. Field Operation
5. Data Reduction Operation
6. Data Analysis Operation

Many individuals had dual functions during the conduct of an experiment, as will be explained later.

The Control Point activities included test direction, forecasting, central communication, tower and portable mast instrumentation, and liaison with the Rawinsonde and Texas A and M Tower operations. The Test Director and Forecaster reported to work at 1600 hours each day to prepare forecasts and schedules for the night's operation. Except for the data reduction group, the remainder of the force reported to work at 2000 hours. By 2000 hours, forecasts and work schedules were transmitted to the Field Servicing Center, Rawinsonde, and Texas A and M Tower operations.

Field Operations headquarters was located at the Field Servicing Center about five miles downwind from the control point. The Servicing Center contained a change room, lunchroom, briefing space, and shop space for the field crew. All field crews were dispatched from this location, assembling here each day at 2000 hours for briefing on the night's schedule.

The Data Reduction Operation worked a regular day-shift schedule, assaying samples and preparing new filters for dispersing to the field crew.

The Data Analysis Operation was charged with continual surveillance of the experimental results to detect possible sources of error and recommend changes in the design of the experiments when they became necessary.

The Control Point for the Green Glow experiments was located in the Hanford Meteorology Building, near the base of the Meteorological Tower. Complete weather-forecasting facilities were available, including teletype and facsimile service. Signals from the tower instrumentation were displayed on a recording panel for continuous appraisal of the current wind and temperature distributions. In addition wind directions and speeds for various locations on the Hanford reservation were received on the radio-telemetering system.

Around the clock (24-hour) forecasting continuity was maintained by the regular forecasters. A special field-test forecaster came on duty at 1600 hours to apply the techniques developed for forecasting the field test conditions as described in Chapter III. By 2000 hours, a forecast was issued to guide the field activities, indicating the probable time that the tracer could be released. All activities were scheduled according to the predicted release time. Surveillance of the meteorological conditions over the test grid continued throughout the course of the experiment. Following tracer release, the estimated location of the tracer plume over the grid area was plotted continuously. This estimated plume movement was used in scheduling sampler operation along the sampling arcs.

The Test Director scheduled operation of the portable mast, Texas A and M towers, rawinsonde releases, generation times, and sampling times; and he transmitted these to the various operating groups. Changes in the schedule were made when required.

Field crews were always briefed at 2000 hours by the Field Director. Tentative schedules for the evening were relayed at this time. In addition any procedural changes or equipment changes were noted at this time. Progress of the test series was covered at these briefings with particular attention given to the previous night's experiment.

Field activities were controlled by radio from the Control Point by the

Field Director upon instructions from the Test Director. Samplers were scheduled to be turned on and off according to zone assignments made earlier. Usually the first four arcs were completely in operation before the pigment was released, with Arcs 5 and 6 delayed somewhat according to the estimated time required for the tracer to reach these arcs. The samplers were checked periodically throughout the sampling period for possible malfunction. Samplers were turned off according to a schedule that assured that the tracer plume had completely crossed the sampling arc. Delays of several hours were sometimes required at the outer two arcs when wind speeds were low. Progress of the sampling activities was continually monitored by the Field Director so that any areas of trouble could be detected and assistance dispatched immediately.

# GEOPHYSICAL RESEARCH PAPERS

GEOPHYSICAL RESEARCH PAPERS (Continued)

# GEOPHYSICAL RESEARCH PAPERS (Continued)

AD
AF Cambridge Research Laboratories, Bedford,
Mass. Geophysics Research Directorate
THE GREEN GLOW DIFFUSION PROGRAM, Vol.I,
by M. L. Barad and J.J. Fuquay(eds). January 1962.
77 pp incl. illus. AFCRL-62-251(I)
Unclassified report

The GREEN GLOW program was a field investiga-
tion aimed at providing experimental data on the
diffusion of an aerosol over a 16-mile range. The
experiments, 26 in number and all during nighttime
hours, were conducted on the Hanford reservation
of the U.S. Atomic Energy Commission, near
Richland, Washington during the Summer of 1959.
The report of this program will be published in two
volumes. This first volume includes descriptions
of the field site, forecasting techniques, diffusion-
measuring methods, meteorological equipment, and
operating procedures during the experiments. The
second volume contains tabulations of the diffusion
data and the meteorological data collected during
the program.

UNCLASSIFIED
1. Diffusion—Measure-
   ment
2. Micrometeorology—
   Measurement
3. Tracer studies

I. Barad, M.L.(ed)
II. Fuquay J.J.(ed)

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